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ORIGINAL ARTICLES.

I.—The Building up of the North Atlantic Tertiary Volcanic Plateau.

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(PLATE XVI.)

IT is many years ago since Sir Archibald Geikie pointed out that the Tertiary basalts of the Western Isles of Scotland and North-East Ireland were remnants of plateaux built up of lavas extruded from fissures after the manner described by von Richthofen. In historic times fissure eruptions have taken place in Iceland, and in *The Ancient Volcanoes of Great Britain* a chapter is included on "The Modern Volcanoes of Iceland as illustrative of the Tertiary Volcanic History of North-Western Europe" (**1**, p. 260). Whilst little remains to be added in support of the very definite analogy exhibited in the nature of the lava streams themselves, the equivalent of the thin bands of red rock so typically intercalated in the Tertiary series has not been particularly examined, and I have visited Iceland in order to study the red beds themselves and search for their counterparts in the modern lava deserts.

The Tertiary Series of Iceland.

The Tertiary rocks of Iceland are similar in kind to those composing the volcanic series of the same age in the British Isles, only the development is on a much grander scale. The observable thickness is 11,000 feet, and how much has to be added on to this, top and bottom, it is impossible to state. The formation consists chiefly of basic rocks. In the east of Iceland acid types are largely developed, attaining in some places a thickness of 2,000 feet. Wherever I have studied them these acid rocks are dominantly extrusive in character. Occasionally remains of plants and trees together with considerable thicknesses of tuff and weathered material occur between the basalts, but these deposits are not particularly under discussion here. Analogous rocks compose the zone separating the upper and lower lavas in North-East Iceland, and their significance has been fully treated of in a recent memoir (**2**). Owing to their economic importance and plant-remains these beds have attracted most attention, but they occur only rarely in the series, the normal development of which is a succession of basalts separated by thin bands of bright-red rock.

A detailed examination of a thousand-foot section at Bægisá, Eyjafjord, North Iceland, showed thirty-eight basalts and partings

of red rock, which gives an average thickness of 26 feet for each flow and its accompanying parting. Two flows were 55 feet thick, one was 6 feet, and one was seen to thin out altogether. The basalts preserve a constant thickness for great distances, but when they thin out they do so rapidly. The interbasaltic layers are composed of a soft colloidal rock a few feet in thickness (commonly two or three feet) and of the variable chemical composition characteristic of the members of the laterite group of rocks. In the present discussion these beds are referred to as 'red partings' to distinguish them from the more varied deposits occurring at rarer horizons.

The prevalent view with regard to these red partings has been expressed by Sir A. Geikie, writing on the Antrim plateau: "It" (i.e. the red interbasaltic layer) "may be looked upon as probably furnishing evidence of the lapse of an interval sufficiently extended to permit a considerable subaerial decay of the surface of a lava-sheet before the outflow of the next lava" (**1**, p. 204). Some, on the other hand, advocate the original tuff nature of the red rock, and, as is pointed out below, this question is of some importance when we attempt to read the history of the Tertiary volcanic period. Thoroddsen writes of the Icelandic series: "Der Aufbau des grossen Plateaus hat ungeheure Zeit beansprucht. Dass die Lavaströme nicht unaufhaltsam übereinander geflossen sind, ist unter anderen aus den zwischen den Basaltdecken befindlichen Verwitterungsprodukten ersichtlich"[1] (**3**, p 232). In the latter part of this paper an attempt is made to indicate more definitely the solution of this problem.

The Red Partings.

As a rule it is only by microscopical examination that the original tuff or lava nature of the red rock can be determined. Its colloidal character makes the preparation of thin slices difficult, though good results can be obtained by using petroleum as a lubricant instead of water. Professor Amund Helland has described thin sections of similar Icelandic rocks, but his paper, written in Norwegian, has escaped notice in Britain (**4**). Several sections were made of specimens taken at random from the Tertiary series. That shown in Pl. XVI, Fig. 1, is of a less weathered rock than usual, and the nature of the parent rock is clearly indicated. A complete petrographic description is not given here, as it is only desired to draw attention to one important point in connexion with the process of palagonitization.

The bulk of the material shown in the section is volcanic glass; one large piece of scoria is seen at 'A'. The glass fragments have characteristic smooth-flowing outlines, those of the scoria being irregular and hackly. The glass is basic, the freshest being light yellow in colour and forming the central parts of the fragments,

[1] "The building up of the great plateaux has taken an enormous time. That the lava-streams were not poured out one upon another continuously is evident, among other things, from the weathered products found between the basalts."

so that the stages in the process of decomposition can be studied by observation to the periphery. The glass becomes brown and red and finally a deep blood-red, this progressive change being accompanied by a progressive increase of refractive index. So far these changes do not affect the homogeneity of the glass, but this condition reaches a limiting point and the glass breaks down. The brown oxide separates into spots, some of which, under a high magnification, are seen to possess asteroid forms. The glass cover was taken off the section, which was placed in a saturated water solution of nigrocene. In half an hour the brown oxide was stained blue. Then the section was immersed in strong hydrochloric acid for seven hours. The yellow and red colours of the glass were removed. The section was then reimmersed in the nigrocene for two hours, after which the original red and yellow glass was stained blue, the stain intensity being a maximum for the first-named. The glass retained its shape, but on probing with a steel point was seen to be plastic. Thus the brown oxide is colloidal, and the glass owes its colour to iron oxide, which can be removed by strong hydrochloric acid. The glass fragments contain occasional crystals of felspar and pyroxene, but these are quite unaltered. This is even the case where the mother glass has been thoroughly broken down and the crystals are left in a matrix of brown oxide.

The most important fact arising out of the petrological inquiry is the resistance offered by the minerals to the weathering agencies and the collapse of the glass. Helland noted how the crystals of felspar and pyroxene remained unaltered in these rocks (**4**, p. 81). The palagonitization process may work so completely in the glass that it finally breaks down, whilst the felspar and pyroxene crystals remain practically unaffected. Whatever the particular rationale of the palagonitic decomposition process may be, glass is far more readily attacked by it than minerals, i.e. volcanic ash than lava. Of course, this follows not only from the lesser resistance offered by the non-crystalline material to the decomposing agencies, but also from its fine fragmental nature, whereby the rock is attacked in all parts at once. Seeing that palagonite rock will take far less time to form from ash than lava, the importance of determining the nature of the original material of the red partings is obvious. (Here we are speaking of the main mass of the lava. The thin frothy upper surface layer of some streams would succumb almost as readily as the ash.)

In the rock just described the original ash character of the deposit is easily seen, but in most of the red partings alteration has been so thorough that it is very difficult and often impossible to settle the question by microscopical examination. If the red rock represented weathered lava, investigation in the field would show a passage to crumbling and decomposing lava surfaces, but I have hardly ever seen clear evidence of this in the case of a basalt covered by a red parting. As there are two or three hundred such partings in the Icelandic Tertiary series, detailed individual examination is out of the question, but further light on them can be obtained from general considerations.

Analogous Deposits of the Modern Lava Deserts.

There is no region which better illustrates the conditions under which the greater part of the Tertiary volcanic series of the North Atlantic lands was built up than the great Ódáðahraun desert which stretches in a northerly direction from the Vatna Jökull, and covers an area of over four thousand square kilometres. It is a plateau of lavas, a stony sea out of which the tuff cones loom like islands. Many of the flows have a ropy surface (see Pl. XVI, Fig. 2). I have never seen such surfaces in the Tertiary series of Iceland, nor do they seem to have been noted in the British Isles—the fact is a curious one.

In the summer of 1914 a journey was made across the Ódáðahraun to the Askja crater, and four circumstances were noted which have a bearing on the problem of the red partings. These are: (1) the fresh and unweathered nature of the lava surfaces; (2) the almost complete absence of plant and animal life; (3) the lack of water; (4) the dust-storms. The freshness of the surfaces of lavas, the outpourings of which we have no historic mention of, was evidenced by the sound metallic clang of the horses' hoofs as they picked their way over the uneven ground. The rough (*aa*) lava surfaces also showed very little evidence of any chemical denudation, though where markedly cindery some mechanical weathering down had produced a black sand. I saw no sign in the Ódáðahraun or in the wastes to the east of Námufjall, Mývatn, of any weathering of lavas giving a product comparable with the red partings. The only equivalent to the latter were the loose fragmental deposits of volcanic ash and sand which covered certain areas. When at rest these deposits are a great boon to the traveller enabling him to make fairly rapid progress over ground that would otherwise be impassable, but they are greatly dreaded when winds arise, being caught up and carried forward as a brown dust cloud. Even in the houses bordering the desert, though door and window be carefully barred, still the fine particles make their way into the room. To quote from Thoroddsen: "Blown sand is of varied quality and origin. It may be coarse or finer; it is sometimes so fine that it penetrates everywhere. During violent storms in sandy districts the fine dust is carried to the most remote quarters of the island and is deposited as a fine layer all over the surface; it even falls on vessels in mid-Atlantic. But naturally most dust falls in districts bordering on the tuff-belt or situated in it, as the dust chiefly originates from the tuff. The atmosphere in distant regions is often yellowish brown because of the fine dust suspended in the air, and this dust cloud is known in Iceland as 'mistur'. This tuff dust has played a very important part in the formation of the Icelandic soil and subsoil, and it can be demonstrated almost everywhere" (**5**, p. 243).

The Interpretation of the Red Partings.

It seems that these fragmental deposits are the equivalents of the majority of the red partings, and that these latter do not represent weathered lava-flows. This conclusion has been felt hard of acceptance by some who have been impressed by the lack of

fragmental product in fissure eruptions, but this objection is removed after a study of the Ódáðahraun deposits. It must be remembered that there is commonly some explosive action accompanying the extrusion of the lava, although the fragmental material thus formed is much inferior in quantity to the latter. Basic tuff cones 500 metres high have been built up in the Ódáðahraun, and by attrition of these and smaller masses the supply of loose material blown about the desert is constantly reinforced. It is not necessary to imagine the red parting to be derived from fragmental material erupted during the extrusion of the underlying basalt; it may belong to an outburst far removed in place and time, or several such. We conceive of these deposits being transported hither and thither over the plains till they happen to be caught and imprisoned by an outpouring of lava. The rising of a wind a few hours before eruption may make all the difference as to whether a basalt is to be accompanied by a tuff or not, and by this interpretation of the red partings we are guarded from attaching too much importance to their occurrence and thickness, which may be purely accidental.[1]

The flooding of basalts and volcanic sand in the manner postulated has been graphically described by W. L. Watts (**6**, pp. 148–56), who had a unique view of the last fissure eruption which took place in the 'Mývatnsöræfi' (a northern continuation of the Ódáðahraun) in August, 1875. Sometimes thin bands of acid tuff are intercalated in the red partings. They may be mere streaks an inch thick, standing out by reason of their lighter colour, and remarkably persistent for considerable distances. One band two inches thick in a parting at Seydisfjord contains well-developed crystals of soda-microcline and soda-pyroxene, minerals common in Icelandic acid rocks. In such cases where the bands are purely acid and contain no basic material they obviously result from a contemporaneous eruption, and it is also clear that the palagonite rock above them is material blown from a distance.

There is one feature that distinguishes the dust deposits of the modern Icelandic deserts from their Tertiary equivalents, and that is their colour. The dust is usually brown, but I have never observed the bright-red tint so characteristic of the old red partings. The colour of these Tertiary rocks is generally taken as an indication that they were formed under warmer climatic conditions than obtain in Iceland at the present day, but that this is not a complete explanation will be evident from the following extract of a letter I received from Professor Thoroddsen in January, 1914: "You will see the red beds almost everywhere in the basalt formation, but not only there; they are also common between the younger dolerite flows which are striated, and probably were outpoured during the Ice Age. I have not done any special investigation of these red beds, but I think they most frequently must be deposits of volcanic ash, and seldom resulting

[1] "If the occurrence and thickness of this layer" (i.e. the interbasaltic red parting) "could be assumed as an indication of the relative lapse of time between the different flows of lava, it would furnish us with a rude kind of chronometer for estimating the proportionate duration of the intervals between the eruptions" (**1**, pp. 254–5).

from subaerial denudation of the vesicular basalt surface like the laterite in India, because in Iceland they are very often found between basalts which have been poured out under the severest arctic climatic conditions."

The want of water and consequently plant, and animal life is forcibly brought home to the traveller in the Odáðahraun, as the food which has to be taken for the horses seriously increases the size of the caravan and prevents any long absence from the grass lands. The lack of plant and animal remains in the Tertiary red partings, which before had presented a rather puzzling feature, is quite understood. Rivers hardly exist on the Odáðahraun proper. The snows of the Dyngjufjöll, a ring of tuff mountains arising out of the desert, give birth to a few streams which soon lose themselves in the holes and gjás of the lava. The general absence of river courses and deposits in the Icelandic series, and indeed of the North Atlantic Tertiary volcanic series, is to be expected. Sir A. Geikie has described deposits and cuttings in the plateau of Western Scotland, due to rivers which are compared with those traversing the Icelandic desert of the present day (1, p. 229). In this connexion it must be remembered that practically all these rivers originate in the great Jökulls, and we have little evidence that ice-caps existed in Iceland in Tertiary times.[1] Even these Jökull rivers flow, not over the lava deserts, but rather over the sand and glacial deposits covering large tracts in the interior of the island, regions more representative of the thick interbasaltic series than of the red partings. The rivers which flowed over the Scottish plateau had their sources in the Western Highland mountains, which provided a large catchment basin sending forth rivers of such a size that they did not readily peter out on reaching the lava plains, but there is no evidence of any such high land bordering the Iceland region.

During the building up of the greater part of the North Atlantic volcanic series we conceive of immense lava plains, covered in places by loose fragmental products. These latter did not always remain stationary, but were liable to be caught up by the wind and carried long distances before being redeposited as a thin mantle covering large areas. This loose material was thrown up during the eruptions and also originated through abrasion of the tuff cones scattered over the plain, and in a subordinate degree from weathering of the scoriaceous surfaces of the lavas. In all probability these plains connected the New and Old Worlds, but commonly there was a dearth of rivers, plants, and animals, and no migration of these latter. At rare intervals vegetation gained a foothold, and "it is not improbable that the basalt plateaux might even be densely wooded"

[1] Dr. Pjetursson has grouped the top series of the Tertiary basalts together as a "Graa Etage", and in them he has discovered ice-scratched surfaces which have led him to advocate the hypothesis of a "Tertiary, possibly early Miocene Ice Age" (7, p. 99) The evidence is as yet too meagre for this hypothesis to be accepted with any certainty, though without postulating a change in absolute mean temperature it would be quite reasonable to imagine that glaciers were formed during the latter part of the volcanic period, consequent upon the elevation of the plateau through successive outpourings of lava.

(**8**, p. 241), though it is unlikely that this condition obtained over the 'land-bridge' in its entirety at any one time; it is more reasonable to conceive of temporary oases, limited in extent, themselves migratory.

The Time represented by the Red Partings.

If the red partings are regarded as weathered lavas it must be recognized that they represent the lapse of a considerable interval of time, for even if they originated under climatic conditions similar to those which obtain in India to-day the growth of the Indian laterite is exceedingly slow. But if these partings are weathered tuffs, which from examination in the field and laboratory, and also by analogy from the deposits of the modern desert of the Ódáðahraun, would seem to be the rule, the length of the inter-eruptive period is considerably diminished for two reasons. One is that, as has been pointed out above, volcanic ash is far more readily attacked by the palagonitic decomposition process than lava, and the other is that the red parting covering a lava may represent material which had been thrown out and blown over the plains long before the outflow of the lava with which it is ultimately associated. Thus we could conceive of two flows extruded in one week being separated by a parting. This is an extreme case, but we have definite evidence that the duration of the period represented by the red partings was relatively short.

At the entrance to the Seydisfjord (East Iceland), between Dalatangi and Shálanes, acid and basic rocks are exposed in a magnificent cliff section which has been figured by Helland (**4**, fig. 10). The main mass of the acid rock is a plano-convex shaped lens of liparite with a maximum thickness estimated at 300 feet, resting on, surrounded, and overlain by an almost horizontal series of basalts and red partings. Underlying the whole of this is a thickness of acid tuff and breccia. The cliff-face is almost vertical, and it was impossible to examine much of the section with the hammer. At one place it was found that the thinner lower exposure of acid rock is a green tuff-breccia, rudely stratified, and containing blocks of basalt and banded liparite up to 2 feet in length. The thick main mass of liparite is a fine-grained greyish rock with prominent flow-banding. At its lower boundary it passes into a black obsidian about 14 feet thick with a breccia-like under-surface. As far as could be seen this obsidian band composes the periphery of the liparite throughout the section, with the exception of the eastern portion, which has been denuded away. The most interesting part of the mass is its western termination, and as it was not possible to land at that point I had to be content with making a sketch which is reproduced in Fig. 3. The relations of the basalts and red partings to the obsidian margin of the liparite are clearly shown. The former retain the approximate horizontality which characterizes the whole of the bedded basalts of the cliff section.

The liparite is extrusive, as shown by—

1. The undisturbed basalts.
2. The nature of the junction of the obsidian and basalts illustrated

in Fig. 3. It would be impossible to conceive such a regular curved boundary to result if the liparite were intrusive. The marked sagging of one of the basalts at *T* is very suggestive of a lava flowing round a hill. We have clear evidence of an acid outbreak in the vicinity before the extrusion of the main mass in the lower tuff-breccia, and our conclusion is strengthened by the similarity of this flow to the post-glacial acid flows of the Torfajökull district described by Thoroddsen (**9** and **3**, p. 155). These lavas are in the main composed of a bluish-grey rock with flow-banding and occasional columnar structure, and grade at the periphery first into obsidian and finally into pumice. The Hrafntinnuhraun stream is a light-grey rock 40–50 feet thick, with an outer shell of obsidian 5–10 feet thick and a final 2–3 feet thick casing of pumice (**9**, p. 612). The Seydisfjord liparite was a surface flow. It formed an eminence on the plain, being gradually surrounded by successive basalt lavas and finally submerged by them. Estimating the liparite as 300 feet in maximum thickness and taking 26 feet as the average thickness of the basalts, twelve of the latter were required to cover it.

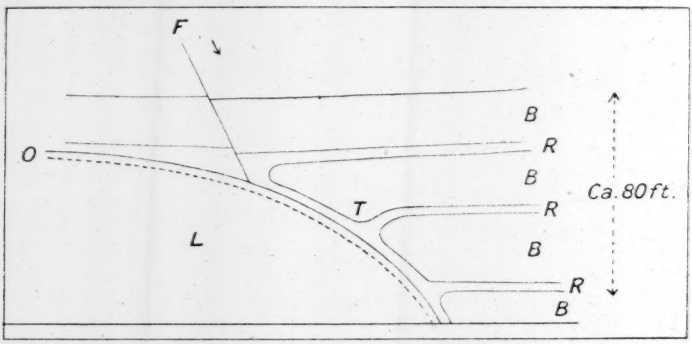

FIG. 3.—Section, western end of the liparite exposure, Shálanes, Seydisfjord. *F* = fault throwing two or three feet; *L* = liparite; *O* = obsidian border to *L*; *B* = basalt; *R* = red parting.

The most important feature is the undenuded character of the liparite. There is no sign of any debris round the hill, and the outer obsidian shell remains intact. The readiness with which liparite is broken up, especially in comparison with basalt, is well known and abundantly illustrated in East Iceland, where basic and acid rocks are so intimately associated and attain such wide development. Acid rocks are fissile and brittle, constantly breaking up and forming scree slopes where no plants gain a footing owing to the ever falling stream of blocks, but the tough basalt is much more resistant and its scree slopes are typically green mantled. Whilst obsidian is more resistant than liparite and provides a protective sheath for acid lavas (**3**, p. 158) the unaltered form of this Seydisfjord flow shows that no great interval of time elapsed during its submergence by the basalts, and also confirms the conclusions reached above respecting the tuff, or rather original fragmental, nature of the red partings, for how

could twelve basalt surfaces be weathered down whilst the acid rock remained unattacked?[1]

Duration of the Tertiary Volcanic Period.

The investigation of the red partings themselves, the analogous deposits of the modern lava deserts, and the Seydisfjord section, all go to show that no great time elapsed between the outpourings of the majority of the basalts. Is it possible to form any idea of the absolute average period of rest?

We have the evidence of the volcanic activity in Iceland in historic times, but the record only stretches over a thousand years, and much of it is uncertain in character. Also the relative intensity of vulcanism in Tertiary times and now must be taken into account. When we conceive of the magnitude of the Tertiary outpourings which probably obtained right across the North Atlantic, forming a land-bridge connecting the Old and New Worlds, and then consider the modern outflows covering what is relatively a very small area, we appreciate the great diminution of activity. It is quite reasonable to suppose that vulcanism so stupendous should, at any particular place, have been manifested more frequently than in the restricted area which has witnessed volcanic activity in historic times. At the last fissure eruption in the Mývatnsörœfi, in 1875, lava was poured out five times from various parts of the fissure (**10**, p. 139). In August of that year Watts observed the flooding of the stream of the preceding April (**6**, pp. 154–5).

Taking all the evidence into consideration, it seems that a thousand years would not be an improbable estimate for the average duration of the inter-eruptive periods represented by the red partings. That this is a liberal allowance will probably be conceded on consideration of what it means in the case of the Seydisfjord section described above, i.e. that in 12,000 years the acid flow suffered no marked amount of denudation. Leaving out of count the longer rest intervals, with the known thickness of the Tertiary formation 11,000 feet, and taking 26 feet as an average basalt thickness, we arrive at a period of approximately half a million years for the building up of the series. It is impossible to say what interval of time is represented by the

[1] These observations are of interest with respect to former discussions on the difficult problem of the age of the Antrim rhyolites. Considering the question of their intrusive or extrusive origin Sir A. Geikie writes: "The rhyolite has been supposed to form the summit of an ancient volcanic dome, perhaps of Eocene age, which had been worn down before the outflow of the plateau-basalts under which it was eventually entombed. Had this been the true history of the locality it is inconceivable that of a rock which decays so rapidly as this rhyolite, and strews its slopes with such abundance of detritus, not a single fragment should occur between the successive beds of basalt which are supposed to have surrounded and buried it. . . . Yet it is clear from the upper surfaces of some of these lavas that a considerable interval of time separated their successive overflows, so that there was opportunity enough for the scattering of rhyolite-debris had any hill of that rock existed in the vicinity" (**1**, p. 428). The relationship of the basalts to the rhyolites in Antrim is very obscure, but in the Seydisfjord section the extrusive nature of the acid rock is quite clear, and arguing from its undenuded surface we conclude that relatively no great interval of time elapsed during the outpouring of the basalts.

rare long periods of quiescence, but there is no evidence that that would be of a different order of magnitude from that required for the rest of the series, and reckoning this interval as as much again we obtain a figure of one million years for the building up of the whole volcanic formation.

What impresses the student of Icelandic geology is not so much the great time which elapsed during the accumulation of the Tertiary series, but rather the long period necessary to allow of the enormous denudation which has obtained. Sir A. Geikie has emphasized this latter point with reference to the British and Færöe Islands: "Among the more impressive lessons which the basalt-plateaux of North-Western Europe teach the geologist, the enormous erosion of the surface of this part of the continental area since older Tertiary time takes a foremost place" (1, p. 455), and from observations on Mull this interval is estimated at twelve million years. For the present purpose this may be taken as a general figure for the whole North Atlantic plateau, although the application to Iceland of the methods by which it was obtained would show a greater interval.

Whilst in absolute amount we can have little confidence in the figure of one million years given for the building up of the plateau, and that of twelve million years estimated for its degradation since the Tertiary volcanoes became extinct, the relative proportion shown by these figures would seem to be correct in kind, if not in degree. When we investigate the Tertiary series of Iceland with respect to the conditions under which it was built up and see how it has been tilted, faulted, and denuded, one fact is clear, and that is, the relative smallness of the time interval which was consumed in building compared with that which has elapsed subsequently—this conclusion doubtless applies to the whole of the North Atlantic plateau. It must be remembered, however, that the dislocation and denudation of the plateau began long before the close of Tertiary times—indeed, the major part was completed before the advent of the Glacial Period.

One of the hindrances in the way of a better understanding of the old Icelandic series is the lack of 'horizons'. It is certainly remarkable that definite horizons should be wanting in such an enormous thickness of rock. The Tertiary volcanic formation is probably unique in this respect amongst all the post-Archæan rocks of the Atlantic countries. The explanation is to be found in the rapidity of building. Per unit of thickness the Tertiary volcanic series represents the smallest time of accumulation of all the post-Archæan formations.

In conclusion, I wish to express my great indebtedness to Professor G. A. Lebour for assistance and encouragement in the carrying out of this investigation, and also to Professor V. M. Goldschmidt, of Christiania, for guidance in the petrographic work.

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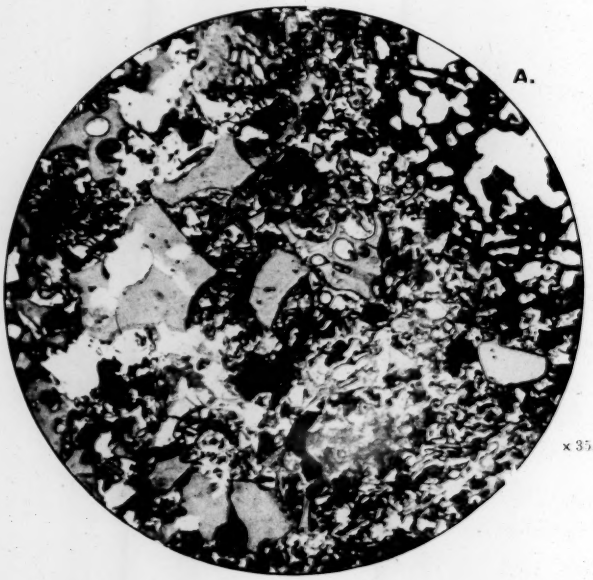

FIG. 1.

FIG. 2.

FIG. 1. Thin section of a red parting, × 35 diam., Bægisá, Eyjafjord, North Iceland

FIG. 2. Ropy Lava, from the Ódáðahraun, Iceland.

4. A. Helland, "Studier over Islands Petrografi og Geologie": Arkiv for Mathematik og Naturvidenskab, Kristiania, 1884, p. 69.
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EXPLANATION OF PLATE XVI.

Fig. 1.—Thin section of a red parting, Bægisá, Eyjafjord, North Iceland. × 35 times nat. size.,
,, 2.—Ropy lava from the Oddáhraun.

II.—The Zones of the Oxford and Ampthill Clays in Buckinghamshire and Bedfordshire.

By A. Morley Davies, A.R.C.S., D.Sc., F.G.S.

I HAVE been studying the zones of the Upper Jurassic clays for the last seven or eight years. Repeated delays from various causes have already diminished the value of the results, and as the work is now held up indefinitely it seems advisable to publish a summary of the conclusions to which I have come, in case the completion of the work may fall to other hands. Such a summary must necessarily be much more dogmatic than I could wish. I have to acknowledge my very great indebtedness, both direct and indirect, in connexion with this work, to Mr. S. S. Buckman.

1. Lower *ornatum* (*jason* or *elizabethæ*) zone.—The lowest zone with which I have met is that characterized by crushed iridescent ammonites, largely of the genus *Cosmoceras*, which are abundantly represented in museums from the railway cutting at Christian Malford, Wilts.[1] This zone was also recorded at Trowbridge, Wilts.[2] It is well shown at Itter's brickworks, Calvert station, Charndon (Bucks), and at several brickworks at Wootton Pillinge (Beds). It seems also to be present in the Peterborough district, at Dogsthorpe, to judge by specimens I have been shown.

2. Hitherto, in England, no clear distinction has been drawn between the above zone and a higher "*ornatum* zone" with equal abundance of *Cosmoceras* but in which the fossils are pyritized. In Bavaria, however, the two are separated by a zone with a very different and well-marked fauna[3]—*Cosmoceras castor* (Reinecke), *C. pollux* (Rein.), *Phlycticeras pustulosum* (Rein.), and species of *Erymnoceras* (the true *coronati*). Traces of this zone may be shown by the occurrence at Trowbridge, Calvert,[4] and Wootton Pillinge of

[1] S. P. Pratt, *Ann. Mag. Nat. Hist.*, viii, pp. 161–5, 1842.
[2] R. N. Mantell, "Strata exposed in the cuttings of the Branch Railway . . . through Trowbridge": Q.J.G.S., vi, pp. 312–13, 1850.
[3] L. Reuter, *Ausbildung des Oberen Braunen Jura im Nördlichen Teile der Fränkischen Alb* (München, 1908), pp. 75–81.
[4] S. S. Buckman, "Kelloway Rock of Scarborough": Q.J.G.S., lxix, p. 159, 1913.

Erymnoceras reginaldi (Morris) in the upper part of the section ; but the most typical members of the fauna are quite unknown in England. Possibly, two zones should be recognized, only the lower (*coronatum* zone) being found in England.

3. Upper *ornatum* or *duncani* zone.—This is the zone with pyritized ammonites, mainly *Cosmoceras* spp. and *Perisphinctes* spp. It is seen at Summertown (Oxford) and at many pits in the Peterborough district, e.g. Eye Green. In Bucks and Beds I have not yet found it, except doubtfully at Woburn Sands. The total thickness of the "*ornatum* zones" is very considerable, and several minor divisions might be distinguished, corresponding generally to those recognized by Judd in the Peterborough district.[1] The Wootton Pillinge district seems to offer the best opportunity of working these out.

4. *Athleta* zone.—The clays which I place in this zone are deficient in ammonites. They contain *Aulacothyris bernardina* (d'Orbigny) and abundant *Gryphæa* which may be identical with *G. bilobata*, J. de C. Sowerby, though after examining a very large number of Upper Jurassic *Gryphæa* I hesitate to give a definite specific name to any. In the two places where I have seen these beds exposed—Ludgershall railway cutting and Eastman's brickworks, Woburn Green—they underlie the well-marked *renggeri* zone. At my last visit to Woburn Green (in July, 1914) I saw one ammonite that suggested that the section penetrated down to the *duncani* zone below, but I was too much occupied with the higher beds (usually quite inaccessible, but then most fortunately measurable in detail) to have any time to examine fully the lower part. Nowhere else have I seen any evidence of the superposition of this zone on any other.

5. *Renggeri* zone. — This zone was well exposed during the excavation of the Ludgershall railway cutting (Great Western Railway, direct Birmingham line). It is also shown in the upper part of the Woburn Sands brickworks, at a small excavation at Aspley Guise (opposite the first houses up the hill from the railway halt), and at the brickfield at Sandy, Beds. From the large collection of fossils from Ludgershall it is possible to state that the fauna is essentially that of Liesberg in the Bernese Jura,[2] with certain interesting minor differences :—

(1) The absence of *Phylloceras*. It is well known that this Mediterranean genus only occurs sporadically in Central Europe and Britain, and less frequently in the latter province than in the former. No *Phylloceras* is known in Britain above the Upper Lias.

(2) The much greater abundance and variety of forms of *Quenstedticeras*, indicating boreal affinities.

(3) The Oppelid *Taramelliceras episcopale* is represented in the Bernese Jura by its typical form only ; in the Ledonian Jura (farther south) it is accompanied by the thicker variety *globosum*, but at Ludgershall thinner varieties predominate.

(4) Cosmoceratids are not found in the Bernese and Ledonian areas; in more northern areas the last species of this family still

[1] J. W. Judd, *Geology of Rutland* (Mem. Geol. Surv.), 1875, pp. 232–6.
[2] P. de Loriol, Mém. Soc. Pal. Suisse, xxv–xxvii, 1898–1900.

survived. This is the case not only in England but in Normandy,[1] and perhaps in South Germany (to judge from some of Quenstedt's figures).

Mr. Buckman has distinguished a *lamberti* zone below the *renggeri* zone,[2] but the evidence on this head is unsatisfactory. There were in the Ludgershall cutting two bands of soft earthy limestone, one highly fossiliferous, the other not. The former contained large specimens of *Quenstedticeras sutherlandiæ* (d'Orbigny) and *Peltoceras* spp. The air-chambers of these fossils are filled with rock-matrix, and the casts are sometimes overgrown with serpulæ and bryozoa, and have been subject to wear and tear subsequent to this encrustation. They certainly indicate a different fauna from that of the *renggeri* clays, but I collected the *renggeri* fauna from below as well as above the stone-beds, although as the collecting was made on a sloped surface the fossils *may* have come from above. At Woburn Sands two exactly similar beds (called *clunch* by the workmen) are found, and here I am quite sure that the *renggeri* fauna occurs *in situ* below as well as above the clunch. The fossils in the clunch, however, are not the same as at Ludgershall. Thus there are several puzzles to be cleared up before we can decide whether the differences of fauna indicate difference of age or difference of conditions.

6 and 7. The pre-*cordatum* zone. — This term was used by Mr. Buckman[3] as a provisional name for the uppermost beds of the Oxford Clay, containing ammonites in some respects intermediate in character between *Quenstedticeras* and *Cardioceras*, having ribs with less geniculation, less tuberculation at the peripheral margin, and less of a forward sweep on the periphery than in the latter genus. Such are Nikitin's species,[4] *rotundatus*, *rouilleri*, *vertebralis*, *tenuicostatus*, *quadratoides*, Lahusen's *nikitinianum*, and possibly his *cordatum* and *excavatum* in part, and de Loriol's[5] *C. cordatum* vars. B to F (perhaps var. A also).

More recently Mr. Buckman has used the term "*scarburgense* zone" in place of "pre-*cordatum* zone".[6] There seem, however, to be at least two zones distinguished by ammonites of this general type. In the lower there are fairly stout species of the *quadratoides* type, preserved as pyritic casts; in the higher, thinner forms with finer ribbing (*tenuicostatum* type) occur with shell preserved. Both zones contain large examples of *Gryphæa dilatata*, auctt.

The lower pre-*cordatum* zone was exposed in ditches on the low ground between Woodperry and Studley, at the brick-field south-east of Studley, in the Great Central railway cutting north of Wotton station, and at the brickfield close to Quainton Road junction. How far it may correspond to any of Mr. Buckman's Yorkshire zones

[1] L. Brasil, Bull. Soc. Géol. Normandie, xvii, pp. 36–49, 1896.

[2] S. S. Buckman, op. cit., p. 159.

[3] In Lamplugh & Kitchin, *Mesozoic Rocks in Coal Explorations in Kent* (Mem. Geol. Surv.), 1911, p. 132.

[4] S. N. Nikitin, *Jura Ablagerungen zwischen Rybinsk, Mologa und Myschkin an der oberen Wolga* (Mém. Acad. Sci. St. Petersburg, xxviii, 1881).

[5] Op. cit., xxv, pp. 14–22.

[6] Q.J.G.S., lxix, pp. 157, 159, 1913, and in *Geology of . . . Whitby and Scarborough* (Mem. Geol. Surv.), 1915, pp. 60, 87.

(*vertumnus, gregarium, vernoni*) I am unable to say, nor can I venture at present a correlation with the late M. Robert Douvillé's sequence at Dives.[1]

The higher pre-*cordatum* zone (perhaps answering to Mr. Buckman's *scarburgense* zone) has been exposed in a well-sinking near Studley[2] and in the Great Western railway cutting immediately north of the tunnel in Rushbeds Wood, Brill.[3] In both these cases the ammonites recorded as *C. cordatum* were finely ribbed forms of the *tenuicostatum* type.

8. The *cordatum* or *vertebrale* zone.—The zone in which the true *Cardioceras cordatum* (J. Sowerby) occurs is only represented in the district under immediate notice by the Arngrove Stone or *Rhaxella*-chert, but westwards it is well represented by part of the Lower Calcareous Grit. The *biarmatum* zone which follows it in the Abingdon district is not found at all to the east.

9. The *martelli* zone (*plicatilis* zone, auctt.).—This is the Upper Corallian of the areas where the coral facies is developed. Apart from its characteristic perisphinctid ammonites, it is recognized by the abundance of *Exogyra nana* (J. Sowerby)[4] in its lowest beds. The calcareous facies of these beds is seen as far east as Wheatley, beyond which there is a sudden change into Ampthill Clay. The basement beds characterized by great numbers of *E. nana* were observed and mapped long ago by Polwhele, and recently by H. B. Woodward, but the finest exposures of them were obtained still later in the railway cuttings at Ashendon junction and Dorton. Here they consisted of varying beds—bluish clay, white limestone, and marly beds full of brown oolite-grains. Some of the latter closely resembled the Elsworth rock except that they were unconsolidated; others, by the abundance of oysters and serpulæ, approached in character the Gamlingay basement bed. Plentiful radioles of *Cidaris smithi*, Wright, with a few of *C. florigemma*, Phillips, linked them with the calcareous beds to the west. They were overlain by over 30 feet of drab clay with beds of soft argillaceous limestone, the clay yielding oysters of the *deltoidea* and *discoidea* types, the stone-beds *Perisphinctes chloroölithicus*, Gümbel, and other *martelli*-zone fossils. In short these railway cuttings link up Polwhele's clay in the most satisfactory manner with the typical Ampthill Clay and its basement beds, including the Elsworth Rock.

Neither Seeley nor Roberts, to whom we are indebted for most of our knowledge of the Ampthill Clay, seems to have questioned its equivalence to the whole of the Corallian. Mr. C. B. Wedd, by his discovery of Elsworth Rock as a base to the Coralline Oolite of Upware, made it highly probable that the Ampthill Clay is Upper Corallian only.[5] H. B. Woodward was cautious in his correlation. He wrote of the abrupt termination of the Corallian stone-beds at

[1] *Cardiocératidés de Dives* (Mém. Soc. Géol. France), 1913.

[2] Davies, Q.J.G.S., lxiii, p. 40, 1907.

[3] Davies, Proc. Geol. Assoc., xx, p. 185.

[4] The holotype of *E. nana* came from the Lower Kimmeridge Clay of Shotover. Should the much commoner Corallian form prove distinct from this, it would probably take the name *Exogyra mima* (J. Phillips).

[5] C. B. Wedd, Q.J.G.S., liv, pp. 614–16.

Wheatley: "This termination has been attributed [by Sedgwick, Fitton, and Hull] to the unconformable overlap of the Kimeridge Clay, but the evidence favours the view that the rock-beds may be largely represented in point of time by sediments of an argillaceous character." [1]

The truth now appears to lie between the two views here referred to. There is an "unconformable overlap", but of the Ampthill Clay, not the Kimmeridge Clay, and over the Lower Corallian. Farther east the break becomes greater. The Arngrove Stone is first overstepped; in the Great Western railway cuttings the *Exogyra nana* beds rest on the *upper* pre-*cordatum* zone; at Quainton Road station typical Ampthill Clay with *Ostrea discoidea*, Kitchin, forms the floor of the goods-yard, while the *lower* pre-*cordatum* zone is exposed in the old brickfield at the same level half a mile to the north-west. I am unable to say which of the pre-*cordatum* zones comes below the Ampthill Clay at Ampthill. At Sandy the *Exogyra nana* beds form the top of the brickfields section (a fact that has hitherto escaped notice) and rest upon the *renggeri* zone.

The gradual overstep of the Oxford Clay zones by the Ampthill Clay is indicated diagrammatically in the accompanying section. If this is compared with the diagram given by Lemoine [2] or those by Reuter,[3] it will be seen that a *martelli*-zone transgression is a phenomenon common to England, North-East France, and Bavaria.

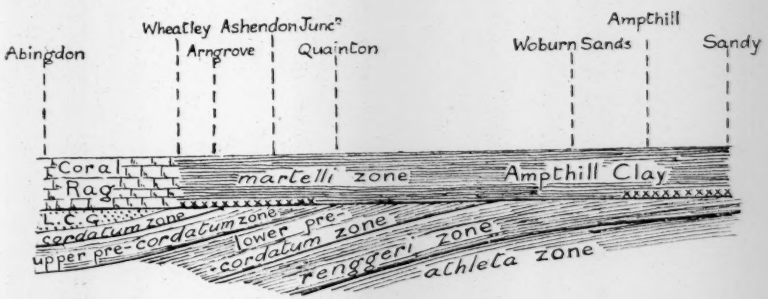


Diagram section along the outcrop of the Coral Rag and Ampthill Clay in Bucks and Beds. Horizontal scale approximately 15 miles to an inch. Thicknesses of zones are entirely diagrammatic. The line of crosses marks the regions where the basement beds of the Ampthill Clay have been observed. L.C.G. = *biarmatum* zone in Lower Calcareous Grit.

What follows the *martelli* zone I am unable to say. There is a distance of only 700 yards between the Great Western railway cutting where the Ampthill Clay was most fully exposed and the brickfield described by me in 1907 [4] and by Messrs. H. B. Woodward and Lamplugh in 1908.[5] The latter authors placed the lower beds of

[1] *Jurassic Rocks of Britain* (Mem. Geol. Surv.), vol. v, pp. 133–5.
[2] *Géologie du Bassin de Paris*, 1911, p. 103, fig. 52.
[3] Op. cit., Textbeilagen H, J.
[4] Q.J.G.S., lxiii, p. 30, 1907.
[5] *Geology of Oxford* (Mem. Geol. Surv.), p. 44.

the brickfield in the Ampthill Clay, but with that I cannot agree. The lowest beds normally exposed in the brickfield belong to a zone which has always been counted in England as part of the Kimmeridge Clay—the zone we have been accustomed to call *alternans* zone, but which Dr. Salfeld has told us is wrongly so called (provisionally I would call it the *serratum* zone). Sixteen years ago I saw deeper beds of clay exposed at the brickfield (in the foundations for the chimney-stack), but I did not recognize any of the beds in the railway cutting as identical with these. There must therefore be some thickness of clay outcropping in the 700 yards between the two exposures, and this may include the representative of Dr. Salfeld's *wartæ* zone.[1]

The mapping of zones along the outcrop of a thick mass of clay is not an easy matter through an inland area, mainly grass-land, but it may be of some practical value. The clays of different zones are not of equal value for brickmaking, or at least not equally suitable for particular processes; and in the selection of a site for new works some means of determining which type of clay will be found at a suitable depth must be desirable. Such a means may be found in a zonal map.

III.—The Contact-Zone of the Alps and the Apennines in Western Liguria.

By C. S. Du Riche Preller, M.A., Ph.D., M.I.E.E., F.G.S., F.R.S.E.

I. Introductory.

In a paper on the Permian formation in the Maritime Alps, etc. (Geol. Mag., 1916, pp. 7–17), I mentioned incidentally that it extends from those Alps, viz. from the Montgioie range east into Liguria as far as the Savona Hills. As in the former so also in the latter region, that formation is composed of essentially gneissic schists known as apenninites or besimaudites belonging to the Lower Permian or Permo-Carboniferous, and of sericitic schists, quartzites, and clastic rocks or 'anagenites' which constitute the Upper Permian or Verrucano proper, forming a transition to the Lower Trias.[2] The geological limit of the Permian in the Savona Hills coincides more or less with the geographical line of division of the Alps and Apennines at the Colle or saddle—also called Bocchetta—d'Altare; but another geological line of division exists still further east, at the junction of the Triassic and Eocene formations in the Chiaravagna Valley near Sestri Ponente, immediately west of Genoa. In reality the geological division is marked, not by either of those lines but by a contact-zone between them. This contact-zone occupies the whole of Western Liguria and comprises two distinct and dissimilar parts: one, the Triassic calc-schists and pietre verdi area or Voltri group, which extends for about 25 kilometres along the Riviera littoral west of Genoa from Sestri Ponente to Voltri, Varazze, and Celle Ligure,

[1] Q.J.G.S., lxix, p. 423, 1913.

[2] This division has its exact equivalents in the Apuan Alps or Carrara Mountains as the lowest formation underlying the marmiferous Trias, and in the Verrucano—a name derived from Monte Verruca—of the Pisan Hills.

and the other or Savona group, which skirts the littoral for about 15 kilometres from Celle to Savona and Zinola, and is composed for the greater part of a crystalline massif of granitic, gneissic, and amphibolic rocks.

Both these self-contained groups present respectively geological features entirely different from those of the adjacent areas east and west. Having examined them both some years ago, I propose to confine the present paper to the crystalline massif of Savona, which, owing to its altogether abnormal position and composition, is of absorbing interest, and has within recent years been the subject of remarkable interpretations as an overthrust zone *par excellence*. The Voltri group I propose to consider in a future paper in connexion with the adjoining ophiolithic area of Eastern Liguria.

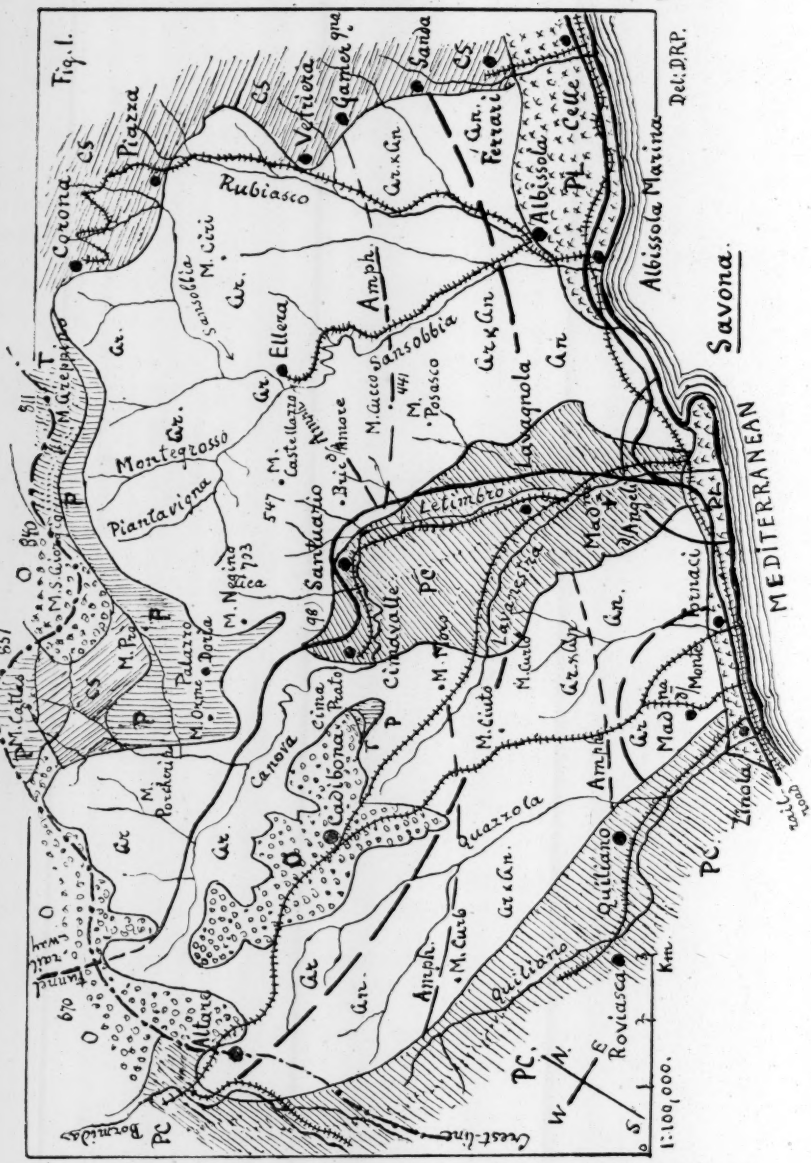
II. General Features. (Fig. 1.)

The Savona Hills form approximately a rectangular area about 15 and 10 kilometres in length and width or 150 square kilometres, its general direction being south-west to north-east. On the south a rugged, craggy wall of gneiss runs along the coastline with some intervening Pliocene deposits at Celle, Albissola, Savona, Fornacci, and Zinola. On the west it skirts, from the coast upwards, the Permo-Carboniferous formation to Quiliano, Roviasca, Monte Curlo, and the village of Altare, a commanding point on the divide between Liguria and Piémont, at about 600 metres altitude. Thence, on the north, it follows the crest-line of the Apennines to Mte. Castlas (851 m.), Mte. San Giorgio (840 m.), and Mte. Greppino (811 m.) to the village of Corona in Triassic and Tertiary strata. On the east, from Corona down to the coast at Celle, the border coincides with the junction line of the calc-schists and pietre verdi of the Voltri group, along which lie the villages of Piazza, Vetriera, Gameragna, Sanda, and Ferrari.

Within this rectangular area the hills rise near the coast to 300 and 400 metres altitude, including Madonna degli Angeli immediately north of Savona, and Madonna del Monte in the south-west corner near Zinola; then in the centre to 500 and 600 metres altitude, notably Mte. Curlo, Mte. Ciuto, Mte. Cucco, and Mte. Castellazzo; and lastly to the crest-line up to 850 metres altitude, including, besides the points already mentioned, Mte. Prà (817 m.) and Mte. Negino (703 m.). The hills are intersected by numerous torrents, generally in deeply eroded ravines, running towards the coast, the principal ones being the Quiliano and Quazzola at the western end, the Letimbro with its affluents the Canova, Gea, and Lavanestra in the centre, and the Sansobbia with its tributaries the Riobasco, Piantavigna, and Montegrosso at the eastern end.

All the localities, points, and ravines mentioned are geologically important for the examination of this extremely complex area, access to which is rendered easy not only by the Savona and Turin railway traversing its central and western part in numerous tunnels and cuttings, but more especially by the roads which run from different points of the Riviera road up into the hills. Among these are the great highway from Savona to Cadibona and Altare into Piémont,

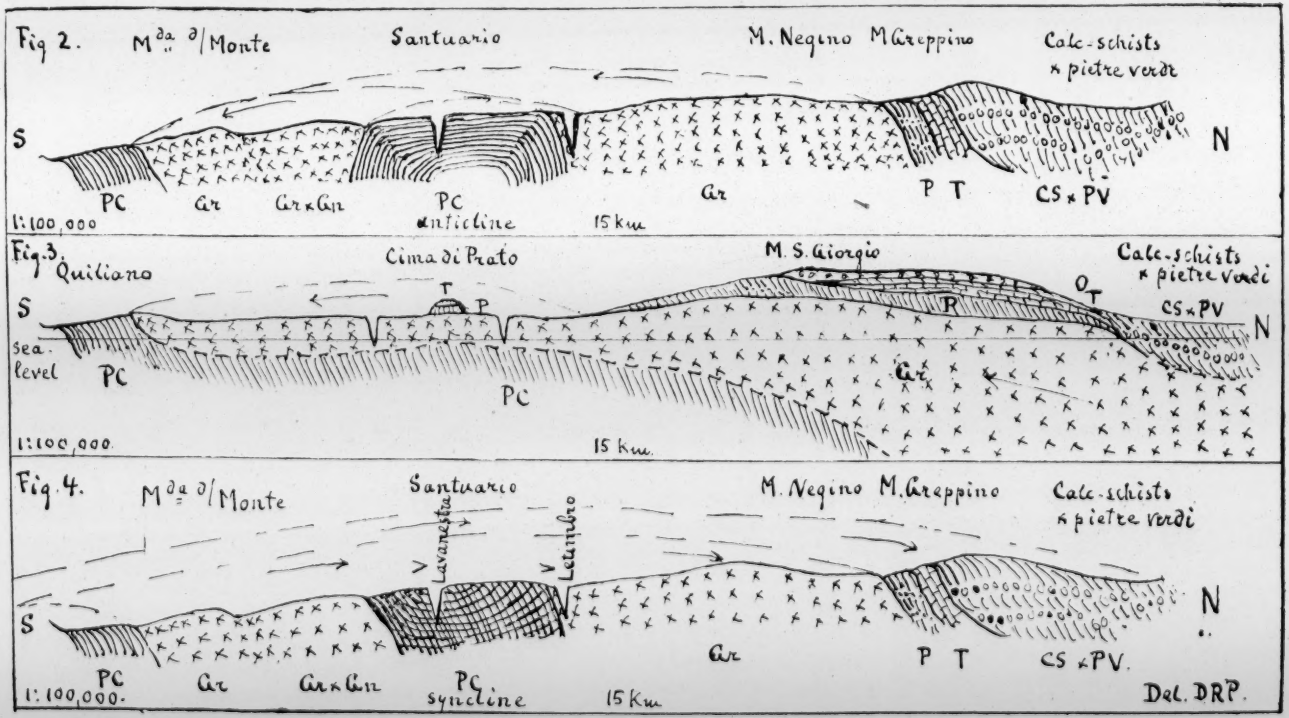
SKETCH-MAP OF CRYSTALLINE MASSIF OF SAVONA.
(Contact-Zone of Alps and Apennines in Western Liguria).



Gr, Gn, Amph.=granitic, gneissic and amphibolic rocks;
PC.=Permo-Carboniferous; P.=Permian;
CS. × T.=Trias; O.=Oligocene; PL.=Pliocene.

SECTIONS OF CRYSTALLINE MASSIF OF SAVONA, WESTERN LIGURIA.

Fig. 2. Local and partial overthrust E. to W. Fig. 3. Exotic wedge-overthrust of whole massif E. to W.
Fig. 4. Overthrust of whole massif from Maritime Alps W. to E.



PC.=Permo-Carboniferous; Gn.=gneiss; Gr=granite; P.=Permian; T.=Trias; O.=Oligocene.

the road to Santuario and Cimavalle in the Letimbro Valley north of Savona; the Quiliano and the Madonna del Monte and Cadibona roads in the western, and those from Albissola to Ellera, to Piazza and Corona, and from Celle to Ferrari in the eastern part of the area. All these roads offer a great variety of interesting and instructive exposures.

III. The Crystalline Massif. (Fig. 1.)

Within the rectangular border-lines of the Permian, Triassic, and Tertiary sedimentary formations, the crystalline massif occupies practically the whole area, with two exceptions. One of these is an island of underlying Permo-Carboniferous gneissic and sericitic schist, about 7 by 4 kilometres in length and width, which stretches from Savona and Madonna degli Angeli north-west to Santuario (98 m.). It has obviously been eroded by the Letimbro and Lavanestra torrents which join a few kilometres above Savona and discharge into the sea at that town. The other exception is a wedge of overlying Permian schist, Triassic limestone, calc-schist with pietre verdi, and Oligocene conglomerate which projects from the north near Monte Ormé and Palazzo Doria to within a kilometre of the Permo-Carboniferous island at its upper or Santuario end. The intervening gap thus forms the superficial connecting link between the two fairly equal parts of the crystalline massif. The only other island in the latter is that of Cadibona in the north-western part of the area composed of overlying Oligocene conglomerates and breccia, at whose eastern extremity occurs at Cima di Prato, west of Cimavalle, an extraordinary isolated outcrop of Permo-Carboniferous schist, mica-schist and gneiss, and Permian schists, surmounted by a cap of Triassic dolomitic limestone.[1]

The anomalous phenomenon which chiefly governs the problem of the Savona region is that the Permo-Carboniferous schists in the south, and more especially those of the Savona and Santuario island, crop out below the crystalline massif, while the Permian and Triassic strata in the north overlie it. The gneissic rocks which occupy the greater part of the southern area are crossed by two bands of amphibolic rocks S.W. to N.E., intimately associated with the gneiss. The whole northern part of the massif, on the other hand, is composed of granitic rocks, which, in the eastern part, are surrounded on the north by a band of Permian schist, and on the south are in contact with gneiss and amphibolic rocks; in the western part the granitic rocks have the same contact as on the south, while on the west the adjacent formations are Permo-Carboniferous schists and Oligocene conglomerates. Granitic rocks also occur among the gneisses and amphibolites, and form a considerable separate mass near Madonna del Monte, in the south-west corner of the area.

IV. The Crystalline Rocks.

The granite when fresh and unaltered resembles in some respects the Alpine type, is often porphyroid and granulitic in structure, of

[1] This outcrop was pointed out by G. Rovereto in a memoir to be quoted later. The small dolomitic cap is obviously in connexion with the larger deposits further north-east.

pale colour, and exhibits as its principal constituents abundant large and medium-sized elements of quartz, plagioclase, considerably or wholly kaolinized, with some orthoclase and subordinate black biotite and muscovite. In a small isolated mass in the north near Pian di Burré, about 500 metres altitude, it is more fine-grained and in part microgranitic. The granitic rocks, both in their fresh, unaltered, and in their far more often altered and friable condition, are well exposed along the Savona and Turin railway in the Upper Letimbro Valley, in the ravines of the tributary torrents Canova and Porcheria, and in Monte Porcheria in the western part of the area. In the eastern part interesting outcrops occur on the eastern flank of Monte Negino, in the Piantavigna and Montegrosso ravines, and notably in the Sansobbia Valley near Ellera, in Monte Ciri, between the Sansobbia and Rubiasco Valleys, and in the latter valley between Piazza and Vetriera along the road from Albissola to Stella.

The gneiss when unaltered is rich in dark brown or black biotite with muscovite, and exhibits large orthoclase and plagioclase elements together with granular quartz. It differs from the Permo-Carboniferous gneiss chiefly in that the latter is more fine-grained, with more muscovite, and paler in colour; but the differentiation is often very difficult.[1] Interesting outcrops of gneiss with associated minute gneiss and mica-schist are those along the coast between Albissola and Savona, where the gneiss is perhaps more unaltered than in other parts of the area; along the Savona and Altare road, in the Lavanestra Valley, where gneisses, amphibolites, and granite alternate; also on the road from Celle to Ferrari and Sanda, on the eastern margin of the area, where the gneiss is in contact with calc-schist and pietre verdi, and in the south-west in the Quazzola Valley and on Monte Ciuto.

The amphibolites are largely derived from pyroxenic rocks with uralitized augite and saussuritized felspar, so much so that often hardly, if any, trace is left of the original constituents. They are closely associated with the gneissic rocks, and differ from the pietre verdi of the calc-schist horizon on the northern and eastern border as much as the corresponding rocks of the Piémontese Alps. Of the two bands which cross the gneissic masses from south-west to north-east the larger one may be traced from the Quazzola Valley to a point where it traverses the road between Monte Ciuto and Cadibona, and then the Savona and Altare road near Monte Moro in the Lavanestra Valley; thence, on the eastern side of the Santuario island to Bric dell'Amore, Monte Cucco, and the Albissola and Ellera road in the Sansobbia Valley. The lesser, more southern band, in contact with the granitic mass of the Madonna del Monte, crosses the road from the latter point to Cadibona south of Monte Ciuto. Some of the best exposures of the principal band occur on the ridge from Savona north to Crocetta, and towards Monte Negino, where the amphibolic banks, notably in Monte Pasasco and north of Monte Cucco, reach a thickness of over 400 metres.

[1] The Permo-Carboniferous gneiss is largely developed in the Quiliano and Roviasca Valleys, in the Bormida Valley west of Altare, and further north-west down to Ferrania di Mare in the same valley; also along the Lavanestra Valley in the Savona and Santuario island.

Between the granitic, gneissic, and amphibolic rocks as the principal constituents of the massif, there are countless passages; all the rocks with rare exceptions exhibit more or less marked evidence of alteration, crushing, and lamination, and intense, often vertical folding, in striking unconformity with the subjacent Permo-Carboniferous and the overlying younger sedimentary formations.

The sedimentary formations comprise, in ascending order, the Permo-Carboniferous gneisses, mica-schists, and the dark, dull sericitic, often green chloritic schists known as phyllades or *schisti plumbei*; the paler Permo-Triassic sericitic schists, quartzites, and clastic Verrucano, including also the lustrous and varicoloured grey, green, and violet *schisti rasati*[1]; and the Triassic dolomitic and fossiliferous, tegular micaceous, and black limestones, the latter corresponding to the grezzoni of the Apuan Alps and belonging to the Middle Trias. These are overlain by the Upper Trias calc-schists with pietre verdi. The extensive deposits of Oligocene fossiliferous conglomerates and breccia on the crest-line and on the flanks of the hills below that line are an important factor as evidence of a marine formation on the former, subsequently raised littoral.

V. The Problem of Age, Structure, and Origin.

This problem has been fruitful of various, often directly opposed interpretations ever since 1841. Sismonda and Pareto regarded the crystalline rocks as primitive and protogine; Gastaldi classed them, including the apenninites, so called by him, as Upper Archæan, though more recent than his calc-mica schist and pietre verdi zone. Zaccagna,[2] and with him Issel and Mazzuoli,[3] in 1887 included the whole crystalline Savona series in the Permo-Carboniferous and Permian horizon of the adjoining Maritime Alps, while De Stefani,[4] in the same year, maintained Gastaldi's view of the Pre-Palæozoic uniformity of all the crystalline rocks of the Western Alps and Liguria.

Since then the most important investigations of the Savona region have been those of Franchi (1893), Rovereto (1895 and 1909), and Termier and Boussac (1911–13), followed by the dissentient views of De Stefani (1913), who confirms his previous ones already mentioned, and considers the Savona massif formed in situ.

1. Franchi, in a valuable memoir,[5] vindicating Pareto's protoginic view, recognized the gneissic, amphibolic, and granitic masses as constituting a crystalline massif older than the Permo-Carboniferous

[1] Rovereto assigns these varicoloured *schisti rasati* to the Middle Trias, but they are, as Termier and Boussac also point out, really Upper Permian.

[2] D. Zaccagna, "Costituzioni Alpi Marittime": Boll. R. Com. geol., 1884, p. 167 et seq.; "Geologia Alpi Occid.": ibid., 1887, p. 346 et seq.

[3] A. Issel, L. Mazzuoli, & D. Zaccagna, *Carta geol. Riviere Ligure*, 1887 and 1890.

[4] C. De Stefani, "L'Apennino fra Colle d'Altare e la Polcevera": Boll. R. Com. geol., 1887, fasc. 3; "Zona Serpentinosa della Liguria Occid.": Atti R. Accad. Lincei, Roma, 1913, pp. 547, 661.

[5] S. Franchi, "Nota preliminare formazione gneissica e sulle roccie granitiche del Massiccio Ligure": Boll. R. Com. geol., 1893, p. 43 et seq. In this memoir Franchi also describes the principal rocks microscopically and gives a list of the literature 1841 to 1893.

and all the other formations of the district. The gneisses and amphibolites he regarded as primitive and the granite as intrusive in, and therefore more recent than, the same. The superposition of the gneiss on the Permo-Carboniferous near Quiliano in the south-west corner of the area is, in his view, due to an inverted fold (*rovesciamento*), the normal sequence of gneiss and Verrucano appearing further north, near Altare. He regards the Savona crystalline massif as forming part of the inner Alpine belt of massifs from Monte Rosa to the Grajan, Eastern Cottian, and Maritime Alps, and the Savona gneisses as akin to those of Gran Paradiso and La Levanna (Grajan Alps) rather than to those of Mont Blanc.

2. Under a novel aspect the problem was presented in an important memoir with maps and sections by Rovereto in 1909.[1] His painstaking survey of both the crystalline and sedimentary formations of the area led him to the conclusion that the reversed, anomalous sequence of the gneiss and the Permo-Carboniferous series is best explained by a local and partial overthrust or displacement of gneissic and granitic rocks from the eastern to the western part of the area. This conclusion he bases on the following grounds:—

(1) That the Permo-Carboniferous island between Savona and Santuario presents all the characteristic features of a 'window' which discloses that formation as the substratum, here assumed to form an anticline.

(2) That in the south-western part of the massif the gneiss mass to which the Permo-Carboniferous strata are adjacent on either side rests against the latter obliquely in opposite directions, and is therefore fan-shaped,[2] whereas the gneiss mass north-east of the Santuario island is essentially isoclinal.

(3) That in that island the eastern contact line of the Permo-Carboniferous schists and the gneiss is comparatively normal and undisturbed, whilst the western contact line exhibits marked unconformity, contortions, and brecciation.

Hence the inference that the eastern part of the crystalline massif is a "rooted" and the western part a "transported" area, viz. a cover-sheet by displacement.[3] The gneisses and amphibolic rocks of the massif are, according to Rovereto, Pre-Carboniferous, and the granite erupted in the Upper Palæozoic.[4]

3. A much bolder and sweeping interpretation of the Savona massif is that of Termier and Boussac in their brilliant memoir of

[1] G. Rovereto, "Zona dei Ricoprimenti del Savonese": Boll. Soc. geol. It., 1909, p. 389 et seq. This memoir was preceded by two preliminary notes on the same subject in 1895.

[2] This fan-structure, shown in general section Fig. 2, rests on the assumption that the adjoining Permo-Carboniferous island on the right is an anticline, not a syncline.

[3] Besides this solution Rovereto adumbrates three others, which, however, he considers less tangible: the first assumes the whole massif to be a rooted, the second a transported area, and the third assumes not only the Savona area but the whole of the Apennines to be a series of transported cover-sheets.

[4] Franchi (op. cit., p. 64) refers to the granite as being on the eastern border intrusive also in the calc-schists and pietre verdi; these being Mesozoic, the granite would be much younger than Upper Palæozoic.

1912.[1] Discarding Rovereto's local and partial overthrust as too timid, incomplete, and wanting in precision, they argue with characteristic *entrain* and incisive style and treatment in favour of a comprehensive overthrust of exotic, long distance origin, and from that point of view the subject is worked out so thoroughly that it will be interesting to outline its salient points.

(1) The extensive examination of the area by the authors leads them to extol the Savona crystalline massif as an ideal 'cover-sheet' region, which, in point of transport and overthrust phenomena, they consider the most typical, unique, and classic of its kind in Europe. All along the roads, in the ravines, and on the heights they find in the abundant examples of intense crushing, lamination, brecciation, and friability of the crystalline masses conclusive evidence that these masses were, by subterraneous transport from an exotic source, wedged between the two sedimentary—the Permo-Carboniferous and the Triassic—formations of the Savona Hills, and thus became the dividing and contact-zone between the Alps and the Apennines.

(2) While wholly adopting Rovereto's view of the Savona and Santuario Permo-Carboniferous 'window', the authors dissent from his lithological distribution of the crystalline rocks, and regard the massif as in the main composed of granitic and only to a very minor extent of gneissic and amphibolic rocks, the proportion of the three being, according to their estimate, respectively $\frac{2}{3}$, $\frac{1}{6}$, and $\frac{1}{6}$.[2] In this estimate they also include a good deal of Permian schist which they regard as altered granitic rock. Of the enormously predominant granitic masses, as also of the gneisses and amphibolic rocks, only a small part is intact and unaltered; the great bulk is altered, structurally and mineralogically, to mylonites, viz. bruised, crushed, laminated, mashed, and brecciated by friction of transport and by dynamic pressure.

(3) The granite when fresh contains 68 per cent of silica and in chemical composition comes near to that of Mont Blanc, but nearer to that of Elba, where Termier already previously claimed extensive granite areas as mylonites,[3] which he correlates with and quotes in support of the phenomena in the Savona region. Of the mylonitic granite the authors enumerate seven varieties or stages between fresh unaltered granite and the most advanced mylonitic rock as the other extreme. The first four stages comprise the fissured and brecciform, the partially crushed and laminated, the intensely laminated, and the incompletely crushed but not laminated rocks,

[1] P. Termier & I. Boussac, "Le Massif Crystallin Ligure": Bull. Soc. géol. France, 1912, p. 272 et seq., with map and 2 sections, preceded by two preliminary notes of 1911.

[2] Rovereto's distribution of granite, gneiss, and amphibolites may be estimated from his map as $\frac{3}{10}$, $\frac{6}{10}$, and $\frac{1}{10}$ respectively, his granite area being less than half that of Termier & Boussac.

[3] P. Termier, "Tectonique de l'Ile d'Elbe": Bull. Soc. géol. France, 1910, p. 314 et seq. The conclusions of this memoir were contested by B. Lotti, "L'ipotesi del Termier sulla tettonica Isola d'Elba," Boll. R. Com. geol., 1910, p. 284 et seq.; and by V. Novarese, "Il presunto piano mylonitico dell'Isola d'Elba," ibid., 1910, p. 292 et seq.

while the last three represent the most advanced types of mylonitization, the rocks being reduced to a trachytic, phonolitic, and, as the last stage, to a talcose aspect, completely mashed and laminated, no minerals being microscopically recognizable. These rocks occur more especially along the friction surfaces of the massif. The seven varieties may be studied along the roads leading from the coast into the hills, and notably along the paths leading from Savona up to Monte Negino in the central part of the area.

4. The cataclastic structure and chaotic condition of the crystalline rocks are, in the author's view, dominant features in favour of the massif being an overthrust *en bloc*. The striking unconformity, often at right angles, between the massif and the underlying and overlying formations, and its wedge-like form, thinning out from 1,000 metres in thickness in the centre to 200 metres at its north-western end, viz. in the direction of thrust, afford evidence not of a merely local and partial displacement but of the exotic origin of the entire massif.

5. The upper transport and friction surface of the massif is, in the author's view, evidenced by the extremely disturbed and brecciated condition of the overlying younger formations in contact with the crystalline rocks. While the upper surface thus forced itself below those formations, the lower surface glided, like a *traîneau écraseur*, along the gently undulating surface of the 'fixed' Permo-Carboniferous substratum. Thus the Savona massif was, in the author's view, transported subterraneously, in a *fuite prodigieuse* (*sic*) from the east, its rooted origin being, in common with the granite massifs of Eastern Corsica and Elba, in the Dinarides.[1]

The two parallel sections south to north, Figs. 2 and 3, illustrate respectively Rovereto's and Termier & Boussac's overthrust interpretations; Fig. 4 represents an alternative interpretation explained at the end of this paper. The sketch-map, Fig. 1, gives, in dotted lines, the approximate zonal direction and distribution of the crystalline rocks; but the countless passages of the three principal rocks preclude any clear definition of limits.

VI. Conclusion.

Without in the least disparaging the overthrust theory *per se*, which in specific cases offers the only tangible explanation of stratigraphical anomalies, it may, in my opinion, be safely averred that as regards the Savona massif, all the individual and collective phenomena so ably marshalled by Rovereto and Termier & Boussac lend themselves with equal, perhaps greater force to a more natural and rational interpretation.

The Savona region, whose crest-line at Mte. Castlas, Mte. S. Giorgio, and Mte. Greppino lies at about 825 metres altitude, forms a depression between Mte. Settepani (1,391 m.) in the Maritime Alps on the west

[1] The theory of the Dinarides being the rooted origin of the three granitic areas is founded on G. Steinmann's often-quoted memoir, "Alpen und Apennin," Monatsber. Deutsche Geol. Ges., 1907, p. 177 et seq.; his "dinaric cover-sheets", however, are assumed to have been transported, not direct from east to west, but circuitously along the curve-line of the Alps.

and Mte. Ermetta (1,267 m.) in the Voltri Apennines on the east. The depression of 500 metres thus constitutes a syncline, in the centre of which the region is deeply cut from north to south, and in its lower part, between Santuario and Savona, is eroded to a width of 4 kilometres by the Letimbro and Lavanestra. In striking contrast to the regularly stratified and undisturbed slopes on the north or Po side of the Apennines, the Savona region is intensely folded, contorted, and faulted, the maximum of disturbance being in the centre, viz. in and near the Letimbro Valley immediately west and north of Santuario, where all the rock formations converge.

As previously mentioned, the northern part of the region is largely covered, in places to a depth of 400 metres, by Oligocene marine conglomerates and breccia which represent a former littoral formation raised in later Oligocene or early Miocene times. It was during that emergence and raising from the sea that the Savona region was, by enormous pressure from below and from both sides west and east, compressed, folded, fractured, brecciated, and, as Termier and Boussac term it, reduced to a chaotic condition, a process repeated on a smaller scale in Post-Pliocene times and followed in each case by a settling which gradually produced the present depression and contact-zone between the Alps and the Apennines.[1]

This enormous compression by repeated earth-movements explains the crushing, lamination, brecciation, and more or less intense alteration of the crystalline rocks, as well as the highly angular unconformity between them and the sedimentary formations, and the marked disturbance of the latter along the lines of contact. The many passages and stages of alteration in the crystalline rocks render a differentiation between transformed granite, gneiss, and amphibolite very difficult; but the granitic rocks being largely predominant and of eruptive origin, it is by no means improbable that the gneissic and amphibolic rocks too are derived from granite which thus constituted the whole original massif.[2] Its eruption and spreading out over the Permo-Carboniferous formation must in that case have taken place about the Middle Permian period, as the Upper Permian or Verrucano in part overlies the massif. This interpretation thus solves without an overthrust the cardinal problem of the abnormal superposition of the crystalline rocks on the Permo-Carboniferous formation.[3]

If, on the other hand, the problem is to be solved by an overthrust, it appears more probable that the whole crystalline massif was

[1] L. Mazzuoli, in an interesting memoir on the "Formazione dei Conglomerati Miocenici nell'Apennino Ligure", Boll. R. Com. geol., 1888, p. 9 et seq., mentions the noteworthy fact that soundings carried out by the Italian Marine Department along the Riviera littoral of Genoa and Savona have proved the existence of submarine river valleys at depths up to 900 metres at 4 nautical miles from the shore. The ratio of fall below sea-level is thus about the same as that from the Apennine crest-line to the coast.

[2] The gneissic rocks of Valdana, in the south-eastern part of Elba, are by common consent of granitic origin, though older than the microgranites in the west of Elba (B. Lotti, op. cit., p. 285).

[3] By this interpretation Termier and Boussac's exotic granite mass, section Fig. 3, whose submarine part is of course purely hypothetical, becomes simply an ordinary intrusive tongue formed in situ.

transported, not from the east, but from a much nearer root in the west, that is, from the Argentera gneiss and granite massif in the Maritime Alps, whence it 'glided' over the intervening Permo-Carboniferous formation of the Montgioie range to its present position probably in Mid-Permian times.[1] The overlying Verrucano, Triassic limestones, and calc-schists with pietre verdi were, in that case, similarly transported from the Montgioie range at a later, probably in the Eocene period, the calc-schists being pushed beyond the Savona massif as a cover-sheet forming the present abnormally located Voltri group.[2] This alternative overthrust is indicated in the section Fig. 4.

The interpretation as an overthrust is alluring, but of necessity hypothetical. It has been truly remarked that there is no difficulty, obstacle, or objection which the overthrust theory cannot overcome by geometrical designs.[3] Rovereto himself calls it *geopoetismo*.[4] When, therefore, a stratigraphical problem admits of a more tangible and legitimate in situ explanation, the presumption and balance should logically be in favour of the latter, and this may reasonably apply to a region geologically so singular and attractive as that of the contact-zone of Savona.

IV.—The Upper Trias of Leicestershire.

(*Continued from the August Number, p. 371.*)

By A. R. Horwood, F.L.S.

(PLATE XVII.)

7. Palæontology.

THIS district is of especial interest from the palæontological point of view in that the different members of the Upper Trias each afford a representative though not extensive flora and fauna. The scantiness of the material, in so far as the Lower Keuper and in some respects the Dane Hill Series are concerned, is due rather to the absence of good sections. This cannot, however, be said of the Rhætic beds, for the section at Glen Parva is one of the finest in the Midlands.

Lower Keuper Sandstones and Marls.

Plant-remains.—In the higher part of the waterstones at Appleby, in the marls intercalated with sandstones, obscure plant-remains, possibly Equisetaceæ, occur.

Annelid or Crustacean tracks.—At Kegworth the surfaces of the sandstones are covered here and there with obscure trails or tracks which may be organic.

Footprints of Cheirotherium.—A footprint, discovered about 1879 by Mr. T. Large, was found at Kegworth in waterstones, which must

[1] The Permo-Carboniferous 'window' would in that case be a syncline, and the adjacent crystalline mass west would be, not fan-shaped, but isoclinal.

[2] Termier and Boussac themselves assume the younger formations to have moved as cover-sheets from west to east, viz. in the opposite direction of the crystalline massif.

[3] V. Novarese, "Il Profilo della Grivola, Alpi Graje": Bull. R. Com. geol., 1909, p. 497 et seq.

[4] Op. cit., p. 408.

be not far from the green beds at the base. It is described and figured in the Appendix (see *infra*, pp. 421–2, Pl. XVII, Fig. 2).

Rhynchosauroid footprints.—Some obscure footprints resembled this type at Kegworth, but are too indefinite to identify with any certainty. In the Building Stones on the opposite side of the River Trent, at Weston Cliff, footprints ascribed to *Cheirotherium* were found years ago. Others were discovered in similar beds at Brizlincote. In the waterstones near Barton, on the Ashby Road, near Mr. Wardle's house, footprints of *Cheirotherium* are also recorded by Molyneux and Sir Oswald Mosley at Barton Bridge.[1]

In the green beds lying over the basal conglomerate at Colwick, Notts, Wilson found *Equisetites columnaris*, and scales of fishes, *Semionotus* sp., and of a palæoniscid type. In the same beds, in the Midland Railway cutting, the Rev. Dr. A. Irving found footprints of a Labyrinthodont.

The officers of the Survey have found obscure remains of plants during their work in the same district. They found annelid tracks at Westhorpe, Dumble, near Southwell, and suggest the possibility of fossils in rocks at Markham Clinton. In the green beds they found obscure remains of plants, and at Farnsfield plants showing cell structure and bits of plants and ill-preserved fish-scales at Boughton Dike.

Upper Keuper Red Marls and Sandstones.

In the Orton-on-the-Hill Sandstone Group so far no plants have been discovered. In the Dane Hill Sandstone Group at Leicester, however, a number of fossils have been found. They were described at an early date by J. Plant, 1849 (Brit. Assoc. Report, 1850), and more fully by his brother, James Plant, in 1856.

Algæ (?).—Some carbonaceous bands, intercalated between sandstones, were said by Plant to be due to Algæ. Certain casts of obscure plant-like structure may be referable to Algæ, but they are not satisfactory enough to place the matter beyond doubt. Well-boring, Leicester.

Equisetites arenaceus.—Certain casts of Equisetaceous plants which are characterized by long internodes and nodes with well-marked furrows may be referred with some reason to the above. There is no resemblance between them and *Schizoneura*, to which certain pith-casts in the Lower Keuper of Bromsgrove are referred by Mr. Wills. Shoulder of Mutton Hill Cutting, Westcotes.

Schizoneura sp.—Dane Hills.

Stigmarites. — A Lycopodiaceous rootlet may be provisionally referred to this genus, though it presents no characters for defining a separate species. Dane Hills.

Voltzia heterophylla.—Specimens found by Plant are referred to *Voltzia*, and in the British Museum a specimen (B.M. 24190) is referred by Professor Seward to the genus, though named *Gorgonia Keuperi*. A cast of the stem is probably referable to this species, and

[1] Coleman refers to these and says that *Estheria minuta* occurs in water stones or white beds.

another may be the male cones, labelled *Echinostachys oblongus*. Dane Hills, Shoulder of Mutton Hill, Leicester.

Incertæ sedis.—A number of other specimens may be doubtfully regarded as plant-remains, some associated with supposed fucoid, or *Gorgonia*, or annelid tracks, or as *Echinostachys oblongus*. In the carbonaceous bands are obscure plant impressions resembling the leaves of *Pterophyllum*.

Annelid or Crustacean tracks.—On the surfaces of the green gritty beds, below the *Acrodus* bed (Annelid bed), are numerous tracks and trails which may be regarded as the work of Annelids or Crustacea. Their mode of occurrence rather than their actual form suggests this, though it is analogous to that of other fossil tracks usually ascribed to Annelids. Well-boring, Shoulder of Mutton Hill, Dane Hills. They occur also in the *Acrodus* beds and *Estheria* marls.

Estheria minuta (Alberti).—Whilst this little bivalved Phyllopod is perhaps most common in the marls above the *Acrodus* sandstones, it occurs throughout the series, and thus ranges from the waterstones to the Rhætic beds. It is often numerous in calcareous marl partings, whilst in the sandstones it is rare. Belgrave, well-boring near west bridge, Shoulder of Mutton Hill, Dane Hills, Aylestone Road.

Acrodus keuperinus (M. & S.).—Dorsal fin-spines of this species are not uncommon in the *Acrodus* beds, and less so in the Annelid beds below, which are the equivalent of Brodie's green gritty marls (Q.J.G.S., 1893, p. 174). Teeth are also to be found in the *Acrodus* beds. Shoulder of Mutton Hill cutting, Dane Hills, Aylestone Road.

Acrodus minimus, Ag.—A dorsal fin-spine found by Browne at Shoulder of Mutton Hill is assigned to *Hybodus minor*, which is in part, according to Dr. A. S. Woodward, to be referred to this species.

Acrodus sp.—Others may be assigned to this genus provisionally from Dane Hills and Aylestone Road, whilst many ichthyodorulites, fish-teeth, and spines may be similarly ascribed to this genus. The coprolites and fish-scales from Leicester, Dane Hills, and Aylestone Road are of more doubtful affinity.

Gyrolepis quenstedti (Dames).—Browne found scales referred to this species at Aylestone Road in the Annelid bed.

Colobodus frequens (Dames).—See the last.

Labyrinthodontia.—A footprint or 'footstep', "4 inches in diameter, in form similar to the well-known Labyrinthodont footmarks of Storeton in Cheshire," was found by Plant in the Annelid beds in the railway cutting at Shoulder of Mutton Hill, and a footmark in the same beds at a well-boring near the west bridge. Plant also found fragments of bone 2 inches thick, 5 inches long, and 1 inch in diameter in the Annelid bed in the cutting, and Browne found others which he ascribes to an amphibian at Aylestone Road. This is interesting as Brodie also found Labyrinthodont bones in the Green Gritty Marls at Shrewley. Plant records them also for the Roman wall boring.

Reptilian remains.—Possibly some of the foregoing should rather come under this head. A fragment of a tooth from Bede House Meadows is certainly reptilian. The fossil referred to, *Tanystrophæus*, Owen, was half a caudal vertebra according to Professor H. G. Seeley,

and not referable to that genus, and later he said it came from the Rhætic.

Red Marl.

Voltzia sp.—Mr. Harrison records the fact that the only fossil he found in the Red Marl was "casts of the spreading leaves" of *Voltzia*. It is probable that careful search, as suggested by Browne, would reveal the occurrence of teeth, etc., of sharks in the skerries and coarse sandstones. The late Mr. G. Lomas found *Estheria minuta* var. *brodieana* in the Red Marl at Oxton, near Liverpool. Near Newark scales of *Gyrolepis* associated with salt pseudomorphs have been found in the grey beds. In some dolomitic skerries there are obscure traces of organisms which might be the casts of mollusca. In marls and clays containing pyrites or allied decomposing agents where sulphuric acid is formed fossils may be dissolved as pointed out by P. M. Duncan. The high proportion of sulphuric acid in the Gypsiferous Marls is in itself a reason for their *apparently* (I would emphasize this word, and endeavour to stimulate research for traces of life at this horizon, rather than discourage it, as is usually the practice) unfossiliferous nature.

Tea-green Marls.

It is due to the last cause that probably the occurrence of fossils in the Tea-green Marls is little known. But though they are not abundant they occur in some variety. They have been found in the West of England and at other places.

In Leicestershire at all of the three principal exposures, Gipsy Lane, Spinney Hills, and Glen Parva, scales of fossil fish have been discovered. They belong apparently to a Semionotoid type. They were especially abundant at Spinney Hills, where the Tea-green Marls were green and blue and buff in colour. With them occur *Estheria minuta* (Alberti) in some quantity. There are obscure remains of what are probably plants and apparently casts of shells.

Mr. Harrison records that he found an insect wing, but he said it perished immediately, and it is more than probable that it was *Estheria*. At the same time the lithic structure is similar to the insect-beds of the Rhætic and Upper Lias, so that, especially as insect remains occur in the Rhætic, not far above the bone-bed, it is less improbable. At the Spinney Hills *Colobodus frequens* (Dames) was found and teeth and scales of a palæoniscid fish.

At Glen Parva there are, as at Gipsy Lane, regular bands of fish-scales, and, in addition to these, *Orbiculoidea townshendi*, Davidson, and annelid tracks have been found by Mr. A. J. S. Cannon. This Brachiopod is common to the Rhætic also.

The continuity of the fauna is, moreover, carried on by the occurrence of true Rhætic fossils in the Sully Beds below the Bone-bed, represented in the West of England and Wales.

Rhætic.

In the notes which follow the localities given are preceded by a number indicating the horizon at which the specimens were found, which is correlated with the Pylle Hill sequence as defined by Wilson.

The same table gives the corresponding beds (by number or letter) of the sections relating to this district as well as that of Stanton-on-the Wolds in Notts for comparison (see Table, p. 419).

Flora.—*Algæ.*

7. Crown Hills. Too indefinite to give any generic or specific name, and possibly (as they are mere casts) something else.

Pterophyllum brevipinna, Heer. Cf. *Otozamites acuminatus* (L. & H.). Intermediate between this and *O. obtusus* (L. & H.). 4. East Leake. 2. Glen Parva.

Plant-remains. Fossil wood. Fragments of stems, branchlets, leaves, possibly in some cases allied to *Podozamites*. 2. East Leake. 2. Glen Parva.

Cœlenterata.—? *Heterastræa rhætica*, Tomes.

2*b*. Spinney Hills. Harrison speaks of "oval markings with fine striæ radiating from the centre", which may possibly be referable to this coral.

Annelida.—*Archarenicola rhætica*, Horwood.

2. Glen Parva. A second specimen has been found.

Annelid remains (tracks and burrows). 2*a*. Spinney Hills. 7–9. Glen Parva.

Crustacea.—*Estheria minuta* (*alberti*). 3. Spinney Hills, Glen Parva. Junction of the Tea-green Marl and Rhætic, Gipsy Lane.

? *Eryma*. Several fragments referable to this genus. 2*b*. Glen Parva.

Insecta.—Coleoptera.

Pterostichites[1] *grandis*, sp. nov. (Pl. XVII, Figs. 1*a*, 1*b*.)

At 3 feet above the Bone-bed at Glen Parva Mr. A. T. S. Cannon found a single elytron of a beetle, associated with fragments of chitin of insects, along with marine shells. As it does not appear to have been hitherto noticed, the following description is given:—

Right elytron, 18 mm. long and 7 mm. broad at the widest part, oblong acute, the anterior and posterior margins subparallel for part of their length; suture following the margin regularly at a distance of less than 1 mm., striæ ten, subparallel, and arising from the proximal extremity at equal distances, converging towards the anterior distal extremity, surface subconvex, coriaceous, the proximal extremity exhibiting a sinus left by the articulatory process.

I am indebted to Mr. T. R. Goddard for confirming my identification of this fossil as a right elytron of a beetle. He considers that it may belong to some form allied to *Pterostichus*, some species of which are marine.

Though such remains are not uncommon in the insect limestone (bed *p* of White Lias) they are rare in the Westbury Beds. They have been found, however, in bed 1 at Stoke Gifford by Dr. A. R. Short in the Upper Rhætic or Cotham Beds.

[1] The genus *Pterostichites* is proposed to include fossil forms presumably related to the modern genus *Pterostichus*.

Gasteropoda.—*Cylindrites ovalis*, Moore. 4. East Leake. I consider *Actæonina valleti*, Stoppani, recorded from here, should be called *Cylindrites ovalis*.

Lamellibranchiata.—? *Leda alpina*, Winkler. Wigston. It is probable that *Nucula variabilis*, Quenst., recorded from here, is referable to this species.

Pteria contorta (Portl.). 2. Ash Spinney, Crownend Wood, Spinney Hills, Barrow-on-Soar, Barrowcliffe, Glen Parva, East Leake, Vulcan Road, Haddon Street, Moat Road, Crown Hill boring. 2*b*–3. Spinney Hills, Billesdon.

Pseudomonotis fallax, Pflücker. 10. Glen Parva, probably from this bed. ?10. Spinney Hills. Cf. *Anomia schafhaulti*, Winkler. 2*b*. Glen Parva.

Pleurophorus elongatus, Moore. 1. Spinney Hills.

? *Myophoria inflata*, Emmerich. 2*b*. East Leake.

Myophoria sp. 2*b*. Glen Parva. Cf. *M. emmerichi*, Winkler.

Chlamys valoniensis (Defrance). 2*b*. East Leake, Glen Parva, Spinney Hills. 2, 4. Wigston, Crown Hill boring.

Dimyodon intusstriatus, Emmerich. 2*b*. Glen Parva (rare).

Volsella minima (Sow.). 2*b*, 10. Glen Parva. 2*b*. Spinney Hills.

Gervillia præcursor (Quenst.). 2*a*, 2*b*. Glen Parva.

? *Gervillia ornata*, Moore. 2*b*. Glen Parva (rare).

Pleuromya sp. (but perhaps *Isodonta*). A "cream-coloured" shell. 2. Culvert between Earl Howe Street and Mere Road in a flaggy band, about 10 feet below the surface.

Myacites striatoglanulata, Moore. 2*b*. Glen Parva (rare).

Astarte sp. Glen Parva (? *A. suessi*, Rolle).

Isocyprina ewaldi (Born.). 2. Glen Parva. 2*a*, 10. Spinney Hills. Glen Parva. 2*b*. East Leake. 4. Glen Parva. 2. Junction of Donnington Street and Mere Road. 7. Diseworth Street.

Protocardia rhætica (Merian). Cottagers Hill. 2*b*. Spinney Hills. 2, 2*b*. Glen Parva. 2*b*. East Leake.

Cardium cloacinum, Quenst. 2. Glen Parva (abundant).

Schizodus depressus (Moore). 1. Spinney Hills. 2*b*. Glen Parva.

Anatina præcursor, Quenst. 2*b*. East Leake.

Ophiolepis damesii, Wright. (Pl. XVII, Figs. 3, 4.) 2*b*. Spinney Hills. Harrison was the first to record this for Britain. But he states that it had been found up to 1880 (*Science Gossip*, 1880, p. 56) at Vallis, Garden Cliff, Stratford-on-Avon, Rugby (in White Lias), Aust Cliff, Penarth to Lavernock, as well as at Hildersheim.[1] He said he considered there were two distinct species, and his specimens include a large and a small form. Wright figured the small form (enlarged), but his description covers the large form. Recently Mr. Cannon brought me a number of specimens from Glen Parva, the large form (Pl. XVII, Fig. 3) from 15 inches above the bone-bed, the small form (Pl. XVII, Fig. 4) 4 feet above

[1] Brodie found it at Summer Hill in Warwickshire, and says it occurs at Westbury midway between the *Estheria* and upper bone beds, and that Wright places it in the Cardium Shales. Wilson found it at Pylle Hill (bed *f*). It was found at Glen Parva, but not in situ, some time ago.

the bone-bed, associated with fish. As Harrison found his specimens with fish also it is probable that this is the same bed, and the small form is no doubt referred to.

I was myself at first inclined to consider there were two species, but more material being forthcoming I came to the conclusion that the species is dimorphic. It may be noted that the large form appears first, the small one later. In this case the small one may be regarded as degenerate, as Mr. Cannon has suggested to me. The opinion I hold is shared by Mr. W. K. Spencer, to whom they were submitted by Dr. Bather, whose advice I had sought upon this point. Dr. Bather, like myself, was inclined to consider the forms distinct, but concurs with my later view, borne out by Mr. Spencer. It is sufficient to remark, at this point, that if the large form is more specialized than the small one, the line of degeneration here is connected with a reduction in the length of the arms, and a relative increase in their width at the base, causing a corresponding decrease in the width of the interbrachial areas. Some other differences are correlated with this. But as it is proposed to publish a separate account of these forms, figures of both are merely given here to show the dimorphism of this species (see Pl. XVII, Figs. 3, 4). Wright's description and figure being in some respects incomplete it will therefore be necessary to amend them. Since the material is not easy to study from the pyritized nature of the matrix, it is hoped further material will throw some light upon obscure points.

"*Echinus*" (? *Pseudodiadema*). Browne mentions that Mr. A. E. Baker found a fragment of an *Echinus* test at Spinney Hills.

Echinoderm ossicles. Barrow Hill.

Pisces.[1]—*Hybodus cloacinus*, Quenst. (teeth and dorsal fin-spines). 1. Spinney Hills. 2. Haddon Street, Crown Hills.

Hybodus minor, Ag. (teeth). 1. Spinney Hills, Glen Parva. 2. East Leake. These are founded on teeth, and the dorsal fin-spines termed *Nemacanthus monilifer* are probably referable to the same species as well as, perhaps, *Sphenonchus*.

Nemacanthus monilifer, Ag. (dorsal fin-spines). 1. Spinney Hills, Glen Parva. 2. East Leake.

Sphenonchus (cephalic spine). 1. Spinney Hills.

Acrodus minimus, Ag. (teeth and spines). 1. Spinney Hills. 2. Haddon Street, Glen Parva, East Leake, Barrow.

Ceratodus latissimus, Ag. (teeth). 1. Spinney Hills. 1. Glen Parva (?).

Gyrolepis albertii, Ag. (scales). 1. Spinney Hills, Glen Parva, Barrow. 2. Haddon Street, East Leake, Glen Parva.

Gyrolepis quenstedti, Dames (scales). 2. East Leake.

Colobodus maximus, Quenst. (teeth and scales). (= *Sargodon tomicus*, Phèn.) 1. Spinney Hills.

Colobodus sp. 1. Haddon Street (scales), Glen Parva.

Sargodon sp. ? 1. Barrow Hill.

[1] See Dr. A. S. Woodward, Trans. Leic. Lit. and Phil. Soc., 1889, p. 18 et seqq.

Saurichthys acuminatus, Ag. (teeth). Regarded by Dr. A. S. Woodward as perhaps the same as *Belonorhynchus*. 1. Spinney Hills. 2. Haddon Street, Glen Parva.

Pholidophorus higginsi, Eg. (= *P. mottiana*, Harrison; *P. nitidus*, Eg.) 2*b*. Spinney Hills, Glen Parva, Crown Hills.

Dapedius sp. 2. East Leake.

Fish-teeth, Fish-bones. 1. Spinney Hills. Coprolites at Glen Parva, East Leake.

Amphibia.—"*Loxomma*" (teeth, vertebræ, rib bones). 1. Spinney Hills.

Labyrinthodont remains (jaw, bones, left ramus of the mandible, teeth, etc.). 1. Spinney Hills. 2. East Leake, Glen Parva.

Reptilia.—"*Plesiosaurus rostratus*" (teeth, bones, ribs, vertebræ). 1. Spinney Hills. 2*b*. Glen Parva. (Probably these belong, according to Dr. Watson, to another species.)

Ichthyosaurus sp. (teeth, vertebræ, bones, coprolites). 1. Spinney Hills (vertebra near Moat Road).

Dinosauria.—2. Limb-bones, East Leake.

Rysosteus oweni, Woodw. & Sherb. 2. East Leake. Dr. Watson considers these may belong to a Plesiosaur as yet undetermined.

Incertæ sedis. Saurian teeth, vertebræ, bones, coprolites, vertebræ of Amphibia or Reptilia, casts of centra, concavo-convex bodies like *Discina*, small circular bodies like cup-corals (at Glen Parva, coprolites). 1. Spinney Hills.

Fragmentary remains of Amphibia and Reptilia. 1. Glen Parva. Saurian Bones and Teeth. 1. Haddon Street.

The correlation of the sections I have given shows that no beds exactly comparable with the White Lias occur in Leicestershire. That the top bed (1 of Richardson) may be the Cotham Marble, however, is shown by its intermediate character, and that *Pseudomonotis* occurs in the upper part of the Compound Bed, and may be equivalent to the *Pseudomonotis* bed as Mr. Richardson suggests, but the rarity of this species makes this point inconclusive. Harrison said he found it at Spinney Hills, and correlates it with a limestone higher up, remarking that he found beds like the Guinea Bed at Crown Hills (Lower Lias).

There is evidence that the Bone-bed, though persistent, and hardly recognizable at East Leake, is a very attenuated type of the West of England equivalent, whilst there were two at Stanton, as elsewhere.

The similarity of fossils at the points named proves the fauna to be, as a whole, uniform. The unfossiliferous character of the Upper Rhætic and anomalous juxtaposition of intermediate beds at the top under beds with *Ammonites planorbis*, *Ostrea liassica*, and *Lima gigantea*, and so close to the Upper Rhætic, as pointed out by Mr. Richardson, in conjunction with gaps between the Tea-green Marls and the Bone-bed, shows that there were locally as elsewhere two periods of alteration of level and conditions.

	Pylle Hill Section (E. Wilson).	Palæontological Reference.	Spinney Hills (Harrison).	Glen Parva (Wilson & Quilter).	Glen Parva (Browne).	Glen Parva (Richardson).	Glen Parva (A. R. H.)	Diseworth Street (Bates & Hodges).	Haddon Street (Fox-Strangways).	East Leake (Browne).	Stanton-on-the-Wolds (E. Wilson).
	Lower Lias . . .	...	...	×	×	× (2–4) *a–c*	× (2–4)	×	...	×	
Upper Rhætic (Cotham Beds). White Lias.	*q*. Limestone . .										
	p. Limestone . .					White Lias absent.					
	o. Shales . . .										
	n. Cotham Marble	10	(?)	3	(?)10–11	1	5				
	m. Shales . . .	9	...	4		2	6				
	l. Limestone (*Estheria*)	8	...			3		All beds below Lias.			
	k. Shales . . .			5	H		7–8				
	i. Limestone . . (*Naiadita*)	7	...			4			...	K	
Lower Rhætic (Westbury Beds).	*h*. Shales (*Pecten*)	6	...	6–10		5*a*–8	9–13				
	g. Limestone . . (*Pecten*)	5	...	11	G	9	14	...	...	J	9
	f. Shales (*Avicula*)	4	...	12–13	F	10	15–18	...	...	E–I	
	e. Shales . . .	3	9	14	E	11	19	...	...		
	d. Shales (*Isodonta*)	2*b*	6–8	15	....	12	20–21	...	...	D	7–8
	c. Sandstone . .	2*a*	5			13	...	...	...	C	6
	b. Shales (*Avicula*)	2	4	16–18	D	14	22	...	2	B	5
	a'. Shales . . .										
	a. Shales and Bone-bed	1	3	19	C	15	23	...	1	...	4
											3
						Sully Beds absent.					2
											1

The disputed point as to whether *Estheria* occurs in the limestone at Glen Parva is somewhat simplified by the fact that Harrison found it at Spinney Hills in the bed in question, and Wilson found *Estheria* in drift derived from these nodular limestones at Stanton-on-the-Wolds.

The outliers of Rhætic beds at Needwood exhibit very peculiar variation. Below what may be regarded as the *Avicula contorta* zone, without a bone-bed, come, in two cases (at Brakenhurst Hill and Buttermilk Hill), 100 feet of white marl with bands of marl limestone overlying red and blue conchoidal Keuper Marls. These white beds must be the Tea-green Marls[1] (proved in the same latitude between Melton and Newark), which have attained an extraordinary development. In the former case the Rhætics are 38 feet, in the latter 24 ft. 7 in. thick, the bulk of which appears to belong to the Lower Rhætic or Westbury Beds. Moreover, at Swilcar Lawn Oak 33 feet of black shales were pierced in a well-sinking. It is thus clear that the northern development of the Rhætics, whilst exhibiting some uniformity in the fauna, is characterized by the absence of beds represented elsewhere to the south, and the greater development of some other beds, pointing to considerable diversity of physical conditions, a fact also demonstrated by the character of the flora and fauna and the state in which it is preserved.

In regard to the White Lias the rather anomalous beds at Glen Parva owe their characteristics to the fact that north of Warwickshire (taking Rugby as an example) the White Lias begins to die out. There would seem, then, to be two different centres of deposition or regions: (1) from Leicestershire to Yorkshire, where more marine conditions prevailed, and (2) Warwickshire to Somersetshire, where estuarine conditions were also prevalent. Probably the southern flora and fauna were derived from the northern, which in turn were derived from the eastern European region. As pointed out by Mr. Richardson, this is, no doubt, due to the fact that the British Rhætic phase is later than the Continental, and no doubt the North British was earlier than the Southern phase, accounting also for the discontinuity of Sully Beds and White Lias.

EXPLANATION OF PLATE XVII.

FIG. 1.—Insecta (Coleoptera).

1*a*.—Right elytron of a beetle, *Pterostichites grandis*, sp. nov. A. R. H.

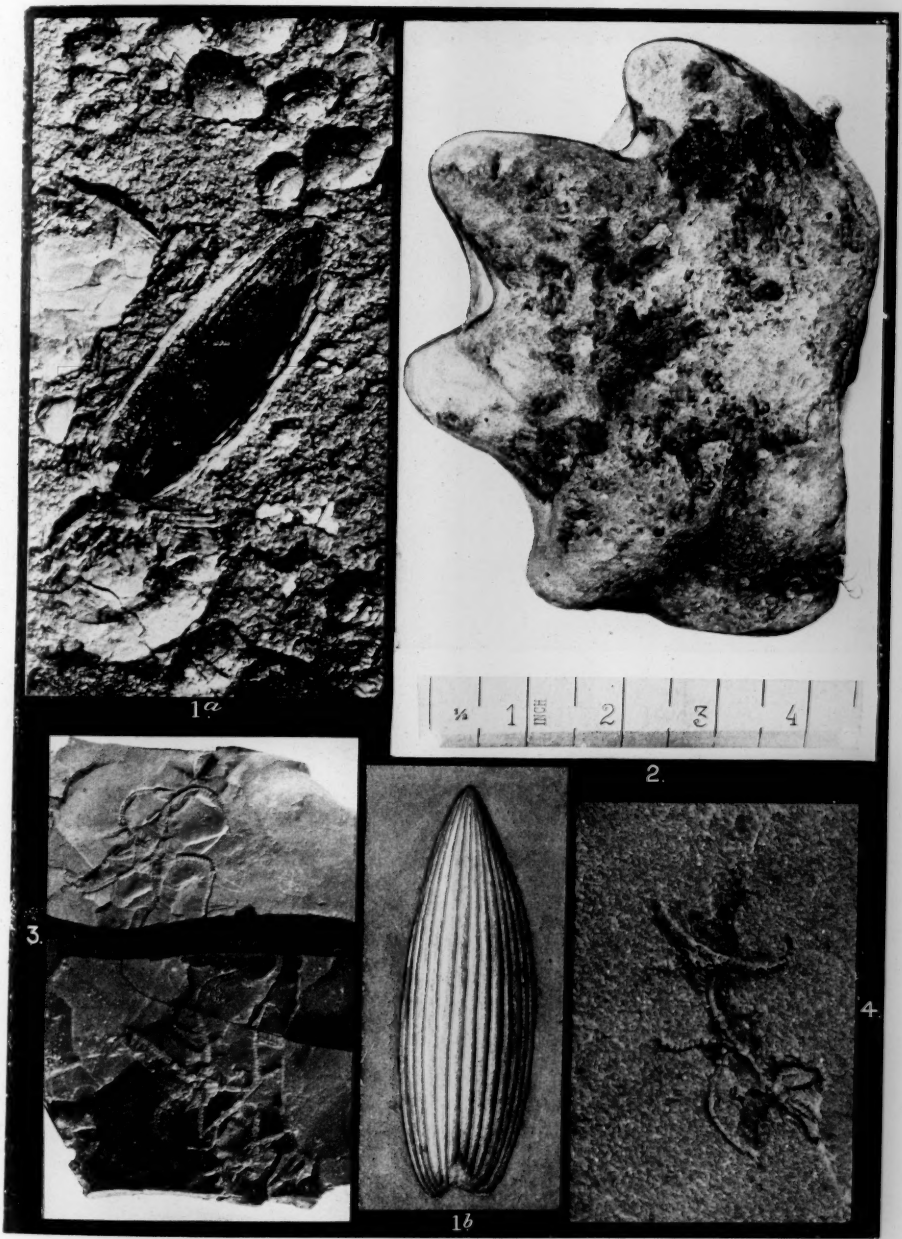
1*b*.—The same restored. From 3 feet above the bone-bed, Lower Lias, Glen Parva, associated with fragments of chitin of insects along with marine shells (see Fig. 1*a*).

FIG. 2.—Natural cast of Chirosauroid footprint (left pes?), form "KP" (Beasley), (reduced). From the Keuper of Kegworth, Leicestershire.

FIGS, 3, 4.—*Ophiolepis damesii*, Wright. Lower Lias: Glen Parva. Fig. 3, the large form (nat. size). Fig. 4, the small form (enlarged).

[1] It is unlikely that they are the Sully Beds in part—missing in Leicestershire and elsewhere.

(*To be continued.*)



A. J. S. Adams, photo.

FOSSILS FROM LEICESTERSHIRE.

V.—Note on the Kegworth Footprint.[1]

By F. T. Maidwell.

(See Pl. XVII, Fig. 2.)

THIS footprint was noticed by Mr. A. R. Horwood in the British Association Trias Committee's Report for 1909 (**5**) and there referred to as resembling *Cheirotherium herculis* (Eg.) and to be from the Lower Keuper Sandstone. As mentioned in that note, it was found in an excavation at Kegworth, North Leicestershire, some thirty-four years ago by Mr. J. Large, who in 1909 presented it to the Leicester Corporation Museum. It is interesting as being the only Chirosauroid print so far recorded from the Keuper rocks of Leicestershire, and proves the occurrence in that area of animals and conditions similar to those which existed in Cheshire, Staffordshire, and Warwickshire during the Keuper period.

The print shows the cast of an impression of four digits with no trace of a fifth. Close behind the first digit the surface is slightly raised and protuberant, but so little that it needs no further notice. The first digit has its origin farther back than the roots of the other toes and is the shortest of the four, the third being the longest. The angle of divergence between the first and second digits is considerably greater than between either the second and third or the third and fourth. The outer edge of the third digit has an inward curve, whilst the fourth is distinctly curved towards the third. Unfortunately a portion of the distal end of the fourth digit has been broken off on its inner side. The digits taper rapidly from their root ends, and in cross-section are slightly rounded on the sides with a slight flattening of the soles. The digits show no trace of pads, but their root ends stand out slightly from the posterior under surface. Short folds can be detected crossing the inner sides of the second and third toes. The digits were deeply impressed towards their distal ends, the greatest depth shown on the cast being about 4 centimetres.

The following are the principal dimensions:—

Length from distal end of 3rd digit to the broken posterior end, 12·5 cm.
Greatest breadth between the distal ends of 1st and 4th digits, 15 cm.
Distance between centres of root ends of digits I and IV, 7·5 cm.
Distance between centres of distal ends: I to II, 6·5 cm.; II to III, 6 cm.; III to IV, 6 cm.

	I.	II.	III.	IV.
Length of digits	2·5	4	5·5	4·7 cm.
Breadth of digits . . .	3·3	5	5	4·5 cm.

[All measurements are given in centimetres.]

In describing a fossil footprint it is always necessary to remember that we are dealing with the impression, or cast of an impression, of a foot and not with the foot itself. The same foot may in the course of a few strides make many different impressions, due mainly to the varying condition of the mud upon which the animal walked.

This footprint probably represents the left pes, but as it is a solitary specimen we cannot say definitely whether it be pes or manus, but

[1] Being Appendix (**11**) to Mr. A. R. Horwood's paper on the Upper Trias of Leicestershire.

the foot which made it was evidently digitigrade. The footprint from Kegworth is not *Chirosaurus herculis* (**2**).

This footprint bears some resemblance to the two groups of Chirosauroid prints which Mr. H. C. Beasley has classified as Group K (**1**, **3**) and Group P (**4**). It resembles the prints of Group K in general outline and two of its digits are curved and also longer

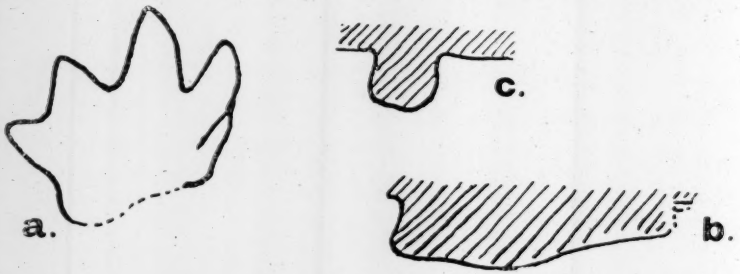


FIG. 1.—The Kegworth Footprint. *a*, Outline of footprint; the dotted line indicates the broken posterior end ($\frac{1}{2}$ nat. size). *b*, longitudinal section of digit III. *c*, cross-section of same digit. See also Pl. XVII, Fig. 2. F. T. Maidwell del.

than wide, but it differs from that group as the digits are not triangular in section, and two of them are neither greater in length than the width at the roots nor are they curved. It resembles those of Group P in that there is evidence of the posterior end gradually merging into the surface of the stone and also in the comparatively short, quickly tapering digits; but it differs from that group in that neither the two outer toes are equal nor are the two inner, and the two digits III and IV curve inwards.

It may be that the prints of these two groups were made by aborted forms of some of the feet which made the five-toed prints in Mr. Beasley's Group A, but at present this is only surmise. So for the present it is advisable to separate these four-toed prints in a group or groups apart, and as this Kegworth print is intermediate in character between the Groups K and P, I propose to label it Chirosauroid footprint, Form KP (Beasley), from the Keuper of Kegworth, Leicestershire.

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1. H. C. BEASLEY. 1898. "Notes on Examples of Footprints from the Trias in some Provincial Museums": Proc. Liver. Geol. Soc., vol. viii, p. 233, pl. xi, fig. 5.
2. —— 1901. "Notes on Type Specimen of *Cheirotherium herculis* (Egerton)": Proc. Liver. Geol. Soc., vol. ix, p. 81, pl. v.
3. —— 1902. "On two Footprints from the Lower Keuper, and their relation to *Cheirotherium storetonense*": Proc. Liver. Geol. Soc., vol. ix, p. 238.
4. —— 1909. "Seventh Report of the Committee for the Investigation of the Fauna and Flora of the Trias of the British Isles. Report on Footprints from the Trias." Part vi. Rep. Brit. Assoc. (Winnipeg), 1909, pp. 151-2, with fig.
5. A. R. HORWOOD. "Preliminary Notice of the Occurrence of Footprints in the Lower Keuper Sandstone of Leicestershire": Rep. Brit. Assoc., 1909, p. 162.

REVIEWS.

I.—The Geology of the Country between Whitby and Scarborough. Second edition. Memoirs of the Geological Survey, 1915. 8vo; pp. iv + 144. London: E. Stanford, Long Acre.

THE second edition of this memoir has been prepared to accompany the new colour-printed map of the district; it has been brought up to date and considerably enlarged, two of the new features being chapters on the palæontological classification of the local Jurassic rocks by Mr. S. S. Buckman and on the fossil plants of the Lower Oolites. The scope of the memoir has also been slightly enlarged by the inclusion of a small triangular area around the town of Whitby, hitherto comprised in the Cleveland memoir.

The geology of this district possesses many features of interest and includes problems which cannot yet be regarded as solved. Two questions, however, stand out before all others in importance, namely, (*a*) the origin and stratigraphical relations of the Blea Wyke beds and (*b*) the glacial phenomena of the district.

With regard to the Blea Wyke beds, recent work by Mr. Buckman, Mr. L. Richardson, and others has shown that the thickness of the strata found at Blea Wyke, but absent elsewhere in North-East Yorkshire, is even greater than was formerly supposed, amounting perhaps to as much as 200 feet. According to the zonal evidence there is probably a non-sequence below the *Nerinæa* bed, which is regarded as the base of the Aalenian, while the Blea Wyke beds proper and *Striatulus* shales are Yeovilian. As is well known, elsewhere the base of the Dogger rests directly on the Upper Lias (Whitbian), the Yeovilian being absent. With regard to the suggestion that the presence of these strata at Blea Wyke only is due to the shelter afforded by the existence at that time of a submarine fault-scarp at Peak, the treatment in this memoir is not satisfactory. The sections devoted to the discussion of this point read like a mosaic of two statements written from opposite points of view. On p. 82 we read, "the suggestion . . . involves many impracticable suppositions. Moreover, the facts to be explained do not arise from the thickening of beds, but from the presence of additional beds not found elsewhere in the neighbourhood." The latter sentence shows a total misunderstanding of the ideas of Mr. Hudleston and others. The supposition of the inter-Jurassic age of the Peak fault was put forward to explain precisely this point, namely, the presence of additional beds, and had nothing to do with variations in the thickness of beds which exist elsewhere. However, at the bottom of the same page the writer of the memoir goes on to accept wholeheartedly the theory which he has just stated to be impracticable. It is shown that in Jurassic times there must have been a fault somewhat along the line of the Peak fault, with a throw of 200 feet. This is a higher figure than was claimed by earlier writers.

Mr. Buckman's work on the Ammonite zones has revealed many points of interest in the correlation of the various members of the Jurassic rocks above the Dogger. It is clear, for example, that the

Cornbrash and Kelloways rock of Yorkshire are not exactly contemporaneous with the strata bearing the same names in the South of England, while the Grey Limestone series appears to belong to the *Blagdeni* zone of the southern district.

The chapter on glacial deposits contains a clear and concise summary of Professor Kendall's views on the modifications of the drainage system of the district during the Ice Age. These are accepted almost in their entirety, with the reservation that "in certain cases it may be questioned whether the existence of extra-morainic lakes can be proved, and whether the streams at the margin of the ice-sheet would not in themselves be sufficient to excavate the channels". This is scarcely to be regarded as an improvement on the original theory: since one of the strongest arguments brought forward by Professor Bonney against the glacial origin of these channels is the difficulty of explaining how a stream whose position is determined by a necessarily shifting barrier like the edge of an ice-lobe could have excavated such clean-cut and steep-sided trenches.

The chapter on economic geology affords somewhat melancholy reading, since it is in the main a record of extinct industries, such as the manufacture of alum, and the working of jet; while, unfortunately, the great ironstone beds of the Middle Lias of Cleveland thin out almost to nothing before they reach the boundaries of the area here described, and the Dogger or Top Seam is for the most part represented by sandstones.

This memoir will be heartily welcomed by all who are already acquainted with the geological features of one of the most interesting districts in the kingdom, while those who wish to acquire this knowledge will find it a mine of accurate and clearly expressed information on all sides of the subject.

R. H. Rastall.

II.—A Text-Book of Geology. Part I: Physical Geology. By Louis V. Pirsson. pp. viii + 444, with frontispiece, 317 figures in the text, and Geological Map of North America. New York, John Wiley & Sons, Inc.; London, Chapman & Hall, Ltd. 1915. Price 10*s*. net.

THIS treatise on geology will, on completion, consist of two parts, the first of which—the one now before us—is by the well-known professor of physical geology in the Sheffield School of Yale University, while the second, under the title of Historical Geology, is to be from the pen of his colleague in the chair of palæontology, Professor Charles Schuchert. Professor Pirsson tells us in his preface that it has been his aim to hold the balance even between physiography, which is the most popular side of the volume and the one most ordinarily studied, and the physical and chemical aspects, which form the real basis of the subject, and he has—we feel no hesitation in saying—successfully achieved his object. The task of the student of geology is akin to the detective's; he has to take the evidence as set before him, and can rarely reconstruct past events. For that reason, in geology theories have been put forward every whit as fantastic as ever

sprang up on the discovery of some sensational and mysterious crime. The increase in the power and range of the modern laboratory has, however, enabled many crucial problems to be isolated and studied in careful detail, and much real progress has been made. The application of the principles of physical chemistry has thrown an illuminating light upon the question of the mode of formation of both igneous and sedimentary rocks. Thus, van t'Hoff and his school have, by their classical researches, cleared up the difficulties that at one time puzzled the student of salt deposits, and the important series of investigations which have for some years past been carried out at the Geophysical Laboratory of Washington upon the conditions under which some of the important and refractory mineral constituents of rocks crystallize out are gradually unravelling the tangled problem presented by the igneous rocks. So much has been accomplished that a new textbook by one who has been so closely in touch with the trend of modern investigations is heartily welcome, and this volume is one which we can thoroughly recommend, not only to the student, but also to the general reader. The author, following a custom which has been extensively followed in recent American textbooks, makes skilful use of two sizes of type, the larger for the more general and important statements, and the smaller for additional or subsidiary detail. We must not omit a note of praise for the numerous excellent illustrations which considerably enhance the value and interest of the book.

Part i of the complete textbook comprises two main divisions: I, Dynamical Geology, and II, Structural Geology. The former, which, as its title indicates, deals with all that has played a part in fashioning the crust of the earth into the form in which we know it to-day, is subdivided into nine chapters. The first is devoted to the atmosphere and its work, and the second to the closely allied subject of rain and running water; the air has powerful mechanical and chemical action, and the water precipitated from it produces rivers, which carving out paths for themselves bear material to the oceans. In the third chapter we read of lakes and interior drainage, and in the fourth of the ocean and its work; as a geological factor the sea acts in much the same way as inland waters, but, of course, on a very much bigger scale, the agencies being currents, tides, and waves. An extremely interesting chapter follows on ice as a geological agent. The contrast between the eroding effect of ordinary weathering and running water and that of glaciation is well shown by three excellent sketches. The final four chapters treat successively of underground water, organic life and its geological work, igneous agencies, and lastly movements of the earth's shell. To human perceptions volcanoes and earthquakes are cataclysmal events, but considered from the geological point of view they are not so important as many other far less awe-inspiring agencies.

The second division, on Structural Geology, which is a little shorter than the first, opens with an introductory chapter on the general structure and properties of the earth. In the discussion of rocks and ore deposits which fills the rest of this division Professor Pirsson not only does not use, but does not even refer to, the ambitious chemical

classification of which he was one of the four authors. He still keeps to the old groups of rocks—sedimentary, igneous, and metamorphic—which have long figured in textbooks; no doubt the wisest course to follow, since, although that arrangement is logically indefensible, petrologists have as yet come to no general agreement on a better one to replace it. The discussion is clear and well expressed, and is rendered very much easier to follow because of the many well-drawn diagrams. In an appendix the most important rock-forming mineral species are briefly described, and a copious index brings the book to a close.

III.—The Geophysical Laboratory.

THREE further papers, dealing with the equilibrium of the systems occurring in igneous rocks, have recently been published. In the first of these[1] the system albite-anorthite-diopside is considered and the equilibrium conditions determined. This system includes mixtures which are comparatively close to certain simple types of igneous rocks such as diorite, gabbro, and basalt, and the results, therefore, are of great interest in petrology. Of the three binary systems concerned, two are eutectiferous and the third conforms to Roozeboom's "type I". The ternary composition-diagram consists of two fields, diopside and plagioclase, separated by a single boundary curve, and there is no eutectic point. The latter fact practically precludes the possibility of any of the above-mentioned rocks representing a eutectic, and the replacement of diopside by complex pyroxene mix-crystals renders the possibility still more remote. This point is of great importance in the theory of crystallization-differentiation, while at the same time it negatives the suggestion that 'ophitic' structure represents a eutectic one. The composition of the plagioclase which crystallizes out varies not only with the original composition of the liquid but also with the rate of cooling. If the latter is not sufficiently slow for the continual attainment of equilibrium, zoning tends to occur, there being a certain rate at which the tendency is a maximum and beyond which it diminishes, until in very rapidly cooled melts it may be absent.

The second paper[2] deals with the system lime-alumina-magnesia, and, as might be expected, is of more importance in the study of Portland cement clinker than in petrology. The chief points of interest are the discovery of a new form of alumina (β–Al_2O_3), which appears to be monotropic with respect to corundum (α–Al_2O_3), and the existence of an almost continuous series of solid solutions between the latter and magnesium spinel. The presence of comparatively large amounts of alumina does not seem to affect the optical properties of the spinel to any appreciable extent.

The third paper[3] contains a critical review of previous work on the

[1] N. L. Bowen, "The Crystallization of Haplobasaltic, Haplodioritic, and Related Magmas": Amer. Journ. Sci., ser. IV, vol. xl, pp. 161–85.

[2] G. A. Rankin & H. E. Merwin, "The Ternary System Ca O–Al_2O_3–Mg O": Journ. Amer. Chem. Soc., vol. xxxviii, pp. 568–88, 1916.

[3] J. Johnston, H. E. Merwin, & E. D. Williamson, "The several Forms of Calcium Carbonate": Amer. Journ. Sci., ser. IV, vol. xli, pp. 473–512, 1916.

various forms of calcium carbonate as well as an account of much new work regarding the conditions under which each form tends to occur. It is shown that under ordinary conditions there are only three definite modifications of the anhydrous salt, calcite, aragonite, and μ–$CaCO_3$, and one hydrated form, the hexahydrate. The various other forms, such as vaterite, conchite, and so forth, are proved to be varieties of either calcite or aragonite. Calcite is the stable form at all ordinary temperatures, but appears to undergo a reversible transformation at 970° to a closely similar modification α–$CaCO_3$. Both aragonite and μ–$CaCO_3$ are metastable under ordinary conditions and tend to pass over to calcite. The rate of the irreversible transformation of aragonite to calcite increases with the temperature, but is very slow at ordinary temperatures. There is no experimental evidence for or against the view that aragonite is the modification stable below zero or under high pressures. The conditions under which the unstable forms precipitate are practically unknown, but the factors favouring their formation include a high degree of supersaturation, the presence of nuclei of isomorphous salts, the presence of sulphate in the solution, and the action of certain organic agencies.

The paper also includes a critical examination of the various methods of distinguishing calcite and aragonite. The cobalt nitrate test, when used alone, is unreliable, as so many other minerals give the same reaction as aragonite and the effect of small quantities of impurities is so great. A similar conclusion is reached with regard to the ferrous sulphate test as well as in those advocated by Thugutt & Niederstadt, where the chief factor which influences the result seems to be the state of division of the material. The authors conclude that the chemical tests are, in general, unreliable and should be substituted by optical ones, which only fail when the material is sub-microscopic.

A. S.

IV.—United States Geological Survey.

BULLETINS Nos. 620 and 621 of the United States Geological Survey constitute Parts I and II of Contributions to Economic Geology, 1915. It is pointed out that there will be no volume corresponding to 1914, because commencing with the present volume the date is that of publication, and not the year in which the field-work concerned was done. The papers in part i relate to minerals and oils, and in part ii to coal and oil. Mr. G. R. Mansfield describes the nitrate deposits in Southern Idaho and Eastern Oregon, which were first discovered in the spring of 1914 in or near the canyon of Sucker Creek, about 16 miles south-west of Homedale, Idaho; deposits have also been found at Jump Creek, about 10 miles further east. The nitre occurs, associated with sodium sulphate, in veins in rhyolitic rocks, but not in sufficient quantity to justify working on a commercial scale.

Mr. Edward L. Jones, jun., briefly discusses the gold deposits near Quartzite, Arizona, close to the Colorado River Indian

Reservation. Placer mining started at La Paz as early as 1862, but was almost entirely abandoned a few years later. The placer areas in Dome Rock Mountains and Plomosa Mountains are composed of intrusive igneous rocks, some of schistose character and others of holocrystalline granitic texture. The schist is believed to be of pre-Cambrian, and the granite probably of Mesozoic age. The belt of cinnabar deposits described by Mr. Adolph Knopf is situated in the heart of the Pilot Mountains, about 8 miles south-east of Mina, Esmeralda County. They came to light in June, 1913, but there were signs of much earlier exploration. The main area comprises the hill now known as Cinnabar Mountain, which is composed of limestones interstratified with dolomitic greywacke. The limestones carry crinoid fragments and other obscure fossils, and are probably of Palæozoic age; the cinnabar is intergrown with calcite and dolomite. Northwards greywacke, slate, and chert form the country rock; here the mineral occurs in a gangue of barytes. Other deposits are situated 6 miles east of Beatty, Nye County, in the Fluorine mining district, partly on Bare Mountain and partly on Yucca Mountain. The general country rock is a fine-grained grey dolomite, of Silurian age, which is massively bedded and much distorted. Cinnabar is associated with opal and alunite. The genetic relation of the cinnabar deposits to the many gold deposits scattered throughout the Western Nevada quicksilver belt constitutes an interesting problem for future research.

Mr. Ernest F. Bouchard describes the iron-ores in Cass, Marion, Morris, and Cherokee Counties, Texas, and also the iron-bearing deposits in Bossier, Caddo, and Webster Parishes, Louisiana. In the first instance the surface rock formations consist chiefly of sand, clay, gravel, and silt. The most recent deposits are of Quaternary age, but the main masses which contain the iron-ore deposits are of early Ternary age (Eocene). The limonite deposits in Louisiana occur mostly in unconsolidated sandy clay and sand, which may be assigned to the St. Maurice formation of the Claiborne group (Eocene).

A reconnaissance of the Cottonwood–American Fork mining region, Utah, made by Mr. B. S. Butler and Mr. G. F. Loughlin, is a description of the ore deposits which will be included in a general report on the entire State, but has been issued separately in advance on account of the exceptional interest now being shown in the region. The silver-lead mines, which were discovered in 1864 and have been worked intermittently ever since, have proved very productive, but the heavy working expenses have previously militated against their success. The sedimentary rocks may be divided into two main groups—the quartzite and shale series, of pre-Cambrian and Cambrian age, and the great limestone series, which is mostly of Mississippian (Lower Carboniferous) age. The two main intrusive bodies of igneous rocks are the Little Cottonwood stock of granodiorite on the west, and the Clayton Peak stock of quartz diorite on the east of the region. The structure of the district is complex, and is characterized by considerable faulting. As a general rule the greatest mineralization occurs towards the top of the intrusive stocks

or in the adjacent sedimentary formations at a corresponding horizon. Mr. G. F. Loughlin describes the recent alunite developments near Marysvale and Beaver, Utah. The feasibility of extracting potassium sulphate from alunite, which is the double sulphate of aluminium and potassium, was demonstrated by Mr. Waldemar T. Schaller, and there appears to be good hope of utilizing it as a commercial source of potash salts; also the alumina obtained as a by-product may prove of commercial value. All the deposits as yet found seem to be veins cutting porphyry (altered dacite); the veins are distinctly banded, nearly pure alunite alternating with quartz.

Mr. Edson S. Bastin and Mr. James M. Hill report on the economic geology of Gilpin County, Colorado. The ores are divisible into five groups: (1) gold-silver ores, the main economic resource of the region; (2) uranium ores, interesting as a source of radium; (3) tungsten ores, forming the basis of the tungsten industry of Beaver County; (4) copper ores, poor in precious metals; (5) titaniferous iron ores, of no commercial value. The entire area is underlain by the pre-Cambrian rocks constituting the core of the Front Range. Probably in early Tertiary time igneous rocks of many varieties were intruded as dykes or stocks. Surface deposits formed by glaciers or streams are the only other formations present.

Mr. W. T. Schaller writes upon cassiterite in San Diego County, California. The pegmatite dyke yielding the cassiterite crops out on the east side of Chihuahua Valley, about two miles south of the boundary between Riverside and San Diego Counties on the edge of the gem district.

In the second part Mr. C. E. Lesher describes a compact and convenient field apparatus for determining ash in coal, which weighs, inclusive of the case, about thirty-four pounds, and measures about a foot cube.

The Healdton oil-field, Carter County, Oklahoma, discussed by Mr. Carroll H. Wegemann and Mr. Kenneth C. Heald, was discovered in August, 1913. The oil has probably been derived from the Pennsylvanian rocks underlying the Permian Series. The accumulation of oil is undoubtedly due to the presence of rock folds. Mr. Wegemann also treats on similar lines of the Loco and Duncan gas-fields in Stephens or Jefferson Counties, Oklahoma. Mr. Eugene Stebinger investigated the geology and coal resources of Northern Teton County, Montana. The coal, which is of medium bituminous grade, occurs in the Two Medicine and the St. Mary River formations. The former with the underlying Virgelle sandstone is identical with the rocks called the Belly River series by Canadian geologists. Fossils are abundant, and include vertebrate, plant, and mollusc remains of many species. The rocks of the St. Mary River formation consist mainly of clay and clay shale, and partly of consolidated sand. Bone fragments of undetermined Dinosaurs are abundant. Mr. Charles T. Lupton describes the oil and gas near Basin, Big Horn County, Wyoming, and Mr. D. Dale Condit the structure of the Berea oil sand in the Woodsfield and Summerfield Quadrangles, Ohio. In the latter instance, the rocks at the surface are included in the Conemaugh and Monongahela formations of the Pennsylvanian

series or the Washington formation of the Dunkard group of the Permian series.

V.—Brief Notices.

1. The Geological Structure of the South Lancashire Coal-field.—In a paper read before the Manchester Geological Society and published by the Institute of Mining Engineers (Trans. Inst. Mining Eng., vol. L, pt. ii, pp. 328–50), Dr. Hickling discusses the general structure of the South Lancashire coalfield, with special reference to the possible occurrence of coal at workable depths below the Permian and Triassic rocks. It is shown that the structure of the coal-basin is remarkably complex, owing to the large number of folds and faults which traverse it. By much patient work this structure has been to a large extent unravelled, and the very important conclusion is reached that a large area of Middle Coal-measures exists to the south and south-west of Manchester, under a cover of Permian and Triassic rocks, which in all probability is not too thick to prevent profitable working. This should lead to important developments in the not far distant future. A second paper by the same author read at the same meeting deals with a small inlier of Lower Coal-measures in Croxteth Park. The result of trial borings was disappointing, as there was no workable coal.

2. Tungsten Ores.—In a paper read before the Chamber of Mines of the Federated Malay States in March last Mr. J. B. Scrivenor gives an account of the occurrences and production of tungsten ores in that region. The tungsten occurs in association with tin ores, chiefly as wolframite, with some scheelite. The wolframite is separated from the tin ores by magnetic processes, but scheelite is non-magnetic and some loss occurs in this way. Unfortunately the outputs are stated only in local weights, *pikuls*, which convey nothing to the ordinary reader. As to the genesis of the ores, it is clear that they are products of pneumatolytic modifications of granite, and in the case of the scheelite of limestones. There seems to be every reason to believe in the possibility of a largely increased output of these ores, which are now in great demand owing to the War.

3. Special Reports on the Mineral Resources of Great Britain. (Memoirs of the Geological Survey.)—The fourth volume of this useful series is devoted to Fluorspar. This mineral has become of considerable importance of late years as a flux in the metallurgy of iron, and large quantities are exported from Britain to the United States. Hitherto the chief source of supply has been the waste-heaps of lead-mines in Derbyshire and Durham, but these are becoming exhausted, and the question now arises to what extent it would be profitable to mine fluor-spar for its own sake. In this memoir descriptions are given of every known occurrence in this country. There would appear to be a possibility of considerable future development. At the present time it is of special importance that a search should be made for fluor-spar of sufficiently good quality for optical purposes, which is now exceedingly scarce and commands a very high price. The fifth volume contains an account of the production in the British Isles of the following useful minerals:

potash-felspar, phosphate of lime, alum-shales, graphite, molybdenite, chromite, talc, and diatomite. In connexion with this list the most pressing need is the discovery of some process to render easily available the vast stores of potash existing in the felspars of the igneous rocks, in order to make this country independent of the German supply of potash salts. Of most of the minerals on this list the British output is now exceedingly small, owing to free importation of foreign material.

4. The Volcanic Rocks of South-Eastern Queensland. (Proc. Roy. Soc. Queensland, 1916, pp. 105–204.)—In this paper Mr. H. C. Richards gives a very interesting account of the volcanic rocks of the south-eastern corner of Queensland, which he shows to be probably of Tertiary age. The rocks are divided into three series, lower, middle, and upper, which are in the main basaltic, rhyolitic, and andesitic respectively. The general composition is clearly sub-alkaline; only in the middle division is there a small proportion of alkaline lavas, pantellerites, comendites, and trachytes, rich in ægirine, arfvedsonite, and riebeckite. These appear to be due to differentiation in the parent magma rather than to assimilation of calcareous material, as advocated by Jensen. The most strongly marked chemical characteristic in all groups is a deficiency of alumina, with a compensating excess of iron oxides. The eruptions were chiefly of the fissure type, though some of the acid eruptions have given rise to tuffs and agglomerates. Contrary to the generally received opinion the Tertiary eruptives of this area constitute a well-marked sub-alkaline province, with only local alkaline episodes. The earth-movements connected with the eruptions are all of the plateau-building type, and there has been no folding since Palæozoic times.

OBITUARY.

EDGAR ALBERT SMITH, I.S.O.,

Late Conchologist of the British Museum.

Born November 29, 1847. Died July 22, 1916.

One of the ablest conchologists of the day has recently passed away in the person of Edgar Albert Smith, who was for more than forty years on the staff of the British Museum. He died at his Acton residence on July 22, in his 69th year. His father was the late Mr. Frederick Smith, a well-known entomologist, and Assistant Keeper of Zoology in the British Museum, Bloomsbury.

Mr. Smith entered the British Museum in 1867, becoming in due course an Assistant Keeper of the Zoological Department, and finally retiring, under the age clause, in 1913. His earlier work at the Museum comprised the arrangement of the famous Hugh Cuming collection of Mollusca, besides which he supervised for some time the whole of the marine invertebrate collections, with the exception of the Crustacea. He was chiefly responsible, however, for the arrangement of the Shell-gallery, which involved considerable care and attention, especially during that period when the natural history collections